# Regional Biosecurity Plan for Micronesia and Hawaii

Volume II

*Prepared by:*
University of Guam and the Secretariat of the Pacific Community 2014

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# Executive Summary

**Prepared by the National Invasive Species Council**

On March 7th, 2007 the U.S. Department of Navy (DoN) issued a Notice of Intent to prepare an "Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS)" for the "Relocation of U.S. Marine Corps Forces to Guam, Enhancement of Infrastructure and Logistic Capabilities, Improvement of Pier/Waterfront Infrastructure for Transient U.S. Navy Nuclear Aircraft Carrier (CVN) at Naval Base Guam, and Placement of a U.S. Army Ballistic Missile Defense (BMD) Task Force in Guam". This relocation effort has become known as the "build-up". In considering some of the environmental consequences of such an undertaking, it quickly became apparent that one of the primary regional concerns of such a move was the potential for unintentional movement of invasive species to new locations in the region. Guam has already suffered the eradication of many of its native species due to the introduction of brown treesnakes and many other invasive plants, animals and pathogens cause tremendous damage to its economy and marine, freshwater and terrestrial ecosystems. DoN, in consultation and concurrence with relevant federal and territorial regulatory entities, determined that there was a need to develop a biosecurity plan to address these concerns.

It is important to note that in February 2012, the United States (U.S.) Department of the Navy (Navy) initiated a Supplemental Environmental Impact Statement (SEIS) to evaluate the environmental consequences of establishing a live-fire training range complex (LFTRC) on Guam in support of the relocation of U.S. Marine Corps (USMC or Marines) forces to Guam (the "LFTRC SEIS"). Shortly thereafter, the U.S.-Japan Security Consultative Committee (SCC) issued a joint statement announcing its decision to adjust the plans outlined in the May 2006 Realignment Roadmap. In accordance with the SCC's adjustments (the "2012 Roadmap Adjustments"), the Department of Defense (DoD) adopted a new force posture in the Pacific, providing for a substantially smaller Marine Corps relocation to Guam.

As a result of the 2012 Roadmap Adjustments, the Navy expanded the scope of the LFTRC SEIS to also evaluate the potential environmental consequences from construction and operation of a main cantonment area, including family housing, and associated infrastructure to support the relocation of a substantially reduced number of Marines than previously analyzed. The SEIS will supplement the 2010 Final Environmental Impact Statement (EIS) for the Guam and Commonwealth of the Northern Mariana Islands (CNMI) Military Relocation. The need for a comprehensive plan to address biosecurity threats posed by the proposed action has not been eliminated as a result of the changes to the force posture.

To address this identified need, DoN has joined forces with partners in other U.S. federal agencies and with local, regional and international governments and organizations to develop a comprehensive Micronesia Biosecurity Plan (MBP). Invasive species are considered the second most significant driver of biodiversity loss worldwide and are by far the number one cause on islands. They also have significant, direct negative impacts upon other critical island issues such as food security, culture, natural resources, economic development and climate change adaptation. Invasive species are spread, intentionally or unintentionally, by trade, travel and tourism. All three of these activities are projected to increase significantly as a result of the USMC relocation to Guam. The projected growth will result in an increased potential to spread invasive species which cause or are likely to cause economic or environmental harm or harm to human health. The development of the MBP is a proactive effort to determine how to best prevent and mitigate the risks of increased invasive species damages as a result of the build-up.

The MBP is unprecedented in its scope and covers invasive species risks from all major taxonomic groups (plants, animals and pathogens) and for all major ecosystems (freshwater, marine and terrestrial) for the vast majority of the region of Micronesia – including Palau, Guam, the Commonwealth of the Northern Marianas Islands, the Federated States of Micronesia and the Republic of the Marshall Islands. Nauru and Kiribati are part of Micronesia but are not included in this analysis because they will not be impacted by the build-up. The State of Hawaii is also being addressed in this effort – but only to the extent to which it will be directly impacted by invasive species concerns related to the build-up.

To develop the MBP, DoN has provided over $3,700,000 in direct funding to scientists and invasive species experts from the Departments of Agriculture and Interior (USDA and DOI), the Smithsonian Institute (SI), the National Invasive Species Council (NISC) and the University of Guam (UOG). The cooperating federal partners (USDA, DOI, SI and NISC) and numerous local and regional cooperators have contributed, and continue to contribute, significant time, resources and expertise to this effort above and beyond the direct funding provided.

This comprehensive approach to biosecurity for the region of Micronesia is a multi-level, multi-disciplinary, collaborative effort, aimed at preventing the introduction and establishment of additional invasive species at both regional and jurisdictional levels. Such a holistic biosecurity plan considers implementation of pre-border (such as pre-clearance), at-the-border (such as inspection and quarantine) and post-border (such as monitoring, rapid response and eradication of invasive species) measures. While all three of these measures are considered critical to an effective biosecurity plan, preventing the establishment of invasive species is most effectively undertaken via pre-border and at the border efforts. Additionally, these efforts are significantly less expensive (in terms of both capital and negative impacts) than long-term control of established invasive species. For many invasive species there are no feasible long-term control options. Left uncontrolled, invasive species and their damage to environment and economy spread and intensify.

The development of the MBP is being conducted in two phases. The overall goal of Phase 1 of the MBP is (1.) to identify terrestrial, marine and freshwater biosecurity risks posed by changes associated with the build-up in transportation and commerce to and within Micronesia and to and from Hawaii, and (2.) to document prevention, control and treatment measures for invasive species that can be incorporated by civilian and military operations. Phase 2 is an ongoing effort with high levels of interest both within and outside of the Micronesia region. It includes the development of an independent scientific peer review of Phase 1 results and creation of a regionally vetted Strategic Implementation Plan (SIP), including extensive in-person consultation with regional invasive species experts and stakeholders. This unique effort will help address both invasive species threats to the military mission and invasive species concerns raised by the Micronesian Chief Executives and federal and regional partners. Phase 1 of the MBP has been completed and this summary is focused on that effort.

Phase 1 was prepared by federal scientists from three different federal departments working in partnership with a variety of other local, territorial, state, national and international invasive species scientists and experts. Experts from the U.S. Department of Agriculture's – Animal and Plant Health Inspection Service (APHIS) addressed terrestrial invasive species concerns and conducted a variety of port examinations. The Smithsonian Institution conducted all work on marine invasive species as well as invasive freshwater plant concerns for the region. Scientists from the U.S. Department of the Interior's – U.S. Geological Survey (USGS) examined invasive issues in regards to the regions freshwater fauna. The National Invasive Species Council (NISC) served as the overall coordinating body during the development of Phase 1. A primary NISC duty was to work closely with DoD counterparts to encourage regional engagement in the MBP process and to facilitate collaboration between local and regional invasive species experts, such as the members of the Micronesia Regional Invasive Species Council, and the federal scientists.

The development of Phase 1 of the MBP marks the first time that scientists from different federal departments have collaborated on such an effort at this scale. It represents a new level of inter-departmental collaboration in invasive species studies and planning that takes advantage of the various centers of invasive species expertise throughout the federal government. The geographic range and taxonomic scope of this effort, combined with the level of intra-federal cooperation and in-depth collaboration with local, territorial, commonwealth, state, and national governments as well as regional organizations truly makes the MBP a globally unprecedented effort. As is often the case when breaking new ground, unexpected challenges and delays arose, but thanks to laudable flexibility from partners and a commitment to the overall goal, these challenges were met and overcome.

Phase 1 of the MBP is composed of a series of documents totaling over 2,000 pages in length. This Executive Summary addresses the MBP Phase 1 document as it was written – breaking it out into its component parts, then providing a synthesis of common "Take Home Messages".

## FRESHWATER ECOSYSTEMS

<u>Macrofauna</u>:
The risk assessment analysis and summary of management alternatives for freshwater invasive animals and their pathways was conducted by a team of scientists from the United States Geological Survey (USGS) led by Drs. Stephen J. Walsh and Leo G. Nico. The USGS Team collaborated with local and regional scientists and experts, conducted numerous field surveys on multiple islands, and examined available data to summarize the status of native and nonindigenous freshwater macrofauna in Micronesia. Using this information, they assessed the introduction risk of new invasive freshwater species into the region, evaluated the pathways by which previous introductions occurred, and identified the species of most concern- i.e., those that have the greatest potential to become invasive in the inland waters of Micronesia. These evaluations and assessments informed the development of management alternatives to prevent or reduce the likelihood of invasion and mitigate the impacts of non-native species already in the region.

The USGS risk assessment used an original data set assembled from a quantitative analysis of fish introductions to the inland waters of Guam and Hawaii. This data set contains information that is much more complete than for any other freshwater taxa or islands in the tropical Pacific. Emphasis was given to the largest islands in Micronesia with the most freshwater resources (as opposed to small islands such as coral atolls with limited or no freshwater resources).

The USGS team found that 1) the aquarium trade, 2) aquaculture, and 3) the live-food trade are the general pathways posing the greatest risk of introduction and spread of invasive freshwater macrofauna. To address these pathways, the USGS summarized 25 specific management strategies, ranked from medium to high priority. The management alternatives are assigned to applicable parties (DoD, non-DoD management and regulatory agencies in Guam and the CNMI, and foreign entities) and are placed into four categories; Prevention/Pathway Disruption, Long-term Management, Early Detection, and Rapid Response.

The analysis by USGS scientists suggested that primary emphasis should be placed on management strategies that address prevention. In order to achieve that goal, a series of actions are suggested that would dramatically improve inspection and detection programs, improve training of inspectors, and establish robust monitoring and rapid response activities. Their asessment also draws attention to the critical need for additional biological surveys, research, and data compilation to allow fuller, more refined analyses of risk and to close data gaps.

Central to all management alternatives summarized by the USGS team is the need for flexibility in implementation. As gaps in the understanding of freshwater invasive species and their impacts in Micronesia are addressed, new technologies and methodologies are developed, and additional invasive species pathways and vectors are identified, biosecurity efforts will need to remain flexible enough to incorporate and take advantage of these advancements in knowledge. USGS identifies certain pathwasy of special concern, such as the availability of potentially invasive freshwater species for purchase over the internet, easy potential for shipment through both the U.S. mail system and private couriers. To close these and other high-risk biosecurity loopholes may require substantial policy and management practice modifications. Lastly, USGS emphasizes the need for broad cooperation and coordination between the U.S. Military, other U.S. Federal agencies, the territorial and sovereign island governments, universities and civilian sectors in Micronesia, and international partners to achieve the biosecurity goals put forth in this document.

<u>Plants:</u>
The risk assessment analysis and development of recommended management practices for freshwater invasive aquatic plant species (IAPS) and their pathways was led by a team of scientists from the Portland State University (PSU) Aquatic Bioinvasion Research and Policy Institute under the leadership of Dr. Mark Sytsma. The PSU risk assessment was conducted by Paul Champion and John Clayton of the New Zealand National Institute of Water & Atmospheric Research Ltd. The PSU team used the results of an exhaustive literature review, supplemented by data collected during field visits and surveys in multiple locations throughout Micronesia, and collaboration with regional experts to inform their risk assessment process and develop their management practice recommendations.

Field visits took place in early 2010 and included surveys of freshwater systems to determine which IAPS were established as well as plants available for sale in pet stores, markets and other commercial venues. As with freshwater animal studies, emphasis is given to the largest islands in Micronesia with the most freshwater resources (as opposed to small islands such as coral atolls with limited-to-no freshwater resources). A notable result of the field surveys was the first record in Micronesia of *Monochoria vaginalis*, a federally listed noxious weed, in a small stream in southern Guam.

Leading up to a detailed discussion of recommendations and specific actions to enhance regional biosecurity for IAPS, the PSU team provides an overview of specific IAPS of concern, susceptible freshwater habitats in Micronesia, IAPS treatment and control methods and current risk management efforts and limitations in the region.

PSU notes that geographic isolation of the islands of Micronesia present unique challenges to the management of IAPS, and that effective biosecurity will need to be coordinated across jurisdictions with understood roles, regulations and opportunities for collaboration. The importance of maintaining programmatic flexibility to be able to incorporate new data and state of the art technologies and methodologies into biosecurity planning is also stressed.
The PSU recommended strategic actions to enhance IAPS regional biosecurity are divided into 5 separate Objectives - each objective containing multiple strategies and each strategy with individual actions.

Objective one is to coordinate and implement a comprehensive management plan. To accomplish this objective, PSU suggests strategies to effectively coordinate and strengthen biosecurity efforts across the region, enhance funding and resources, and maintain flexibility so that regional and international lessons learned, advances in understanding and new preventative methodologies can be incorporated into regional and local biosecurity planning.

Objective two is to prevent new freshwater IAPS introductions and spread of existing species. To accomplish this objective, PSU suggests strategies to address five critical pathways of IAPS introduction: internet/mail order, ornamental water features, tourism, military equipment and personnel and air and maritime cargo. Two additional strategies focus on improvement of detection and interception if IAPS as well as the development of plans to control high-risk IAPS already present in the region.

Objective three is to detect and monitor for freshwater IAPS. To accomplish this goal, PSU suggests a strategy to implement standardized IAPS surveys of regional freshwater habitats to enable more effective prevention, eradication and control efforts.

Objective four is to coordinate and implement a comprehensive early response plan.To accomplish this objective, PSU suggests strategies to enable swift identification and response to regional IAPS incursions and to develop efficient, coordinated eradication efforts based on accurate delineation, clearly stated management goals and informed selection of eradication methods.

Objective five is to inform public, policy makers, and user groups of risks and impacts of IAPS.

To accomplish this objective, PSU suggests strategies to enhance outreach and education to three targeted groups in the region. Effective public education can decrease intentional and unintentional IAPS introductions and outreach and training provided to natural resources personnel and networks of interested citizens can be important components to early detection and monitoring efforts.

MARINE ECOSYSTEMS:

A team lead by the Smithsonian Environmental Research Center (SERC) prepared the marine ecosystems component of Phase 1 of the MBP. The SERC document outlines risks of invasion and provides recommendations to reduce the introduction, establishment and spread of marine and estuarine invasive species. In preparation of this document SERC teamed with other Marine invasive species experts from Central Queensland University, Portland State University and the Bishop Museum.

The SERC document is composed of three basic parts. Part one presents information on the present understanding of vectors (such as vessels and live trade) by which non-native marine species are transferred into Micronesia and provides a summary of current regulations and management practices to address those vectors. Part two is a risk assessment of marine invasions for Micronesia and details likelihoods and consequences of invasion. Part three provides a marine biosecurity plan for the region including specific recommendations on actions, strategies and frameworks to be implemented to minimize damages to Micronesia from marine invasions. The SERC document focuses heavily on vectors of invasion and vector management is presented as a critical component of the marine biosecurity plan itself. The risk assessment focuses on biofouling organisms – i.e. those organisms known to foul the hulls and underwater surfaces of vessels - and incorporates information on shipping traffic patterns and history of commercial and U.S. military vessels. Critical information regarding a large proportion of U.S. Navy vessels was not made available to the SERC team to evaluate, due to its sensitive nature. Data for recreational and fishing vessels was also lacking..

Unique to the SERC document is a pilot study on Micronesian societal values towards invasive species impacts. The pilot study sought to identify known and perceived values (environmental, economic, social and cultural) that may be impacted by introduced marine species and then assess the perceived change in these values if invasive marine species were to occur in the region. Typically, and especially in the U.S., risk assessments do not incorporate social and cultural impacts. This preliminary examination shows that there is concern over social and cultural impacts of marine invasive species.

The SERC marine biosecurity recommendations start off with a review of general biosecurity and marine-specific plans that have been developed or proposed in the broader Pacific, within Micronesia and for U.S. military bases. SERC then provides a conceptual framework with four components (and the interactions among them) of marine invasive species vector management ((1). Vector analysis, (2). Vector strength, (3). Vector interruption (disruption) and, (4). Efficacy), noting that a successful biosecurity program must incorporate each of these components along with necessary policy, management and research to sustain them.

SERC provides 47 marine invasive species prevention recommendations for vector management broken out by particular vectors ranging from a variety of vessel types (military, commercial, fishing, recreational, etc.) to construction materials, diving and fishing equipment and live trade of marine organisms. Recommendations for vessels are categorized into the specific issues of ballast water, biofouling and compensating fuel tanks (the last for military vessels only).

For ballast water, SERC makes a variety of recommendations to ensure consistent and coordinated data collection and reporting, treatment requirements, field-based treatment validation surveys and education efforts to ensure familiarity with goals and requirements. Of note is the need for a clear policy that clarifies what ballast water practices are required for all military vessels, regardless of military branch or port of origin, as currently there is significant uncertainty and ballast water management and discharge practices are unknown for many military vessels. Also of note is the need for sufficient personnel, training and data management infrastructure to implement and evaluate ballast water management at commercial ports throughout Micronesia.

For biofouling, SERC recommends, as the highest priority, the need for DoD to inspect all military vessels with high likelihood of biofouling (due to high port residence times) and to effectively clean all military vessels that are heavily fouled before they are allowed to move into, out of, or within Micronesia. It is also recommended that DoD determine criteria for acceptable levels of hull biofouling for all military vessels (including amphibious) as well as any vessels under contract to the military (including barges, dredges, etc.). For commercial vessels (including barges, cruise ships, yachts and fishing vessels), SERC again recommends the establishment of requirements for acceptable hull biofouling and in-water cleaning methods as well as routine biofouling inspection, certification and reporting standards. SERC also recommends that targeted outreach efforts be initiated to inform both military and commercial vessel audiences of biofouling management requirements.

SERC stresses that commercial vessel biosecurity requirements must also apply to any commercial fishing vessels that operate in Micronesia. Outreach programs should be implemented to target DoD and civilian populations on guidelines and methods to minimize biosecurity risks associated with kayaks, outriggers, diving gear, and recreational fishing gear. Biosecurity requirements and practices should also be developed for grounded vessels, in-water structures such as dry docks, drilling rigs and fish aggregating devices because they can pose a very high, if infrequent, risk of marine organism transfer to and within the region. SERC also recommends the establishment of explicit biosecurity measures for aquaculture as well as the establishment of a formal risk assessment process, quarantine facilities and effective reporting, screening and enforcement capacity throughout the region to minimize risk of marine organism transfer from live organism trade.

In order to establish effective marine invasion detection capacity, SERC stresses the fundamental need to develop standardized, quantitative and repetitive field-based surveys of non-native marine species in harbors, bays and ports throughout the region. SERC recommends the establishment of a high-risk species watch list for the region and a detection and response plan focused on a few of these identified high-risk species. Further evaluation of economic and social values (per the pilot study initiated in this report) would enhance and refine decision processes for management and priorities for response to invasive marine species incursions.

SERC's last comments address implementation of their recommendations and development of capacity necessary for that implementation. Implementation should, where possible, be addressed as a coordinated, integrated approach across disciplines and jurisdictions. This integrated approach would allow for more efficient use of resources and greater effectiveness and consistency of efforts. For example, although the document provided separate vector management recommendations for DoD and commercial vessels, many aspects of reporting, training, infrastructure and legal frameworks could be effectively and efficiently combined. Specifically, SERC recommends creating a single Micronesia-wide program – a Micronesia Marine Biosecurity Facility – to serve as a resource center to provide training, shared protocols, outreach initiatives and to help identify funding opportunities and build capacity. SERC also recommends formal Memoranda of Agreement (MOU) between Micronesian governments and DoD departments to establish plans and command structure to respond to incipient marine invasions. SERC also recognizes that development of capacity and resources should be a major focus of the implementation plan (MBP Phase 2).

SERC ends by discussing the visionary scope of the MBP effort, noting the advancement of regional biosecurity across multiple countries and cultures provides an important model that uses "an appropriate spatial scale at which invasions operate." Successful implementation of a cohesive regional plan to address marine invasions would make "DoD and its partners across Micronesia...world leaders in advancing marine biosecurity, especially in tropical ecosystems."

## TERRESTRIAL ECOSYSTEMS

The U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) prepared the entire terrestrial ecosystem component of the MBP. APHIS is a multi-faceted agency with a broad mission and a diverse set of expertise. To address the wide array of knowledge and disciplines necessary to comprehensively address invasive species threats to terrestrial ecosystems for the MBP, over 30 scientists and experts from three different APHIS agencies (Plant Protection and Quarantine (APHIS -PPQ), Wildlife Services (APHIS -WS) and Veterinary Services (APHIS-VS)) collaborated in developing this report.

There are multiple frameworks that scientists use to assess risks. Recommendations to prevent and mitigate invasive species risk can vary depending on the taxa under consideration and evaluation framework employed. Given the tremendous diversity and scope of evaluating all terrestrial invasive species risks, the APHIS document includes two separate sets of risk assessments and recommendations. The first risk assessment was conducted by APHIS-PPQ and informs the plant, pathogen and insect recommendations that were developed jointly by APHIS-PPQ, APHIS – VS, and APHIS-WS (wildlife disease scientists). APHIS – WS (terrestrial vertebrate scientists) conducted the second risk assessment and developed the terrestrial vertebrate recommendations. For the purposes of this Executive Summary, the work of all APHIS risk assessments and recommendations are synthesized together.

APHIS provides a thorough overview of operational considerations that should be addressed in route to developing a biosecurity program that integrates biosecurity activities in the Micronesian Region under single management framework. Cooperative, centralized management of biosecurity would improve efficiency and effectiveness of efforts by presenting opportunities for synergy, developing unified strategies and consistent outreach, and enhancing communication and cooperation amongst public, private and military sectors.

APHIS risk assessments examine impacts from the military relocation and provide evaluations and risk ratings for a variety of species of concern and pathways such as aircraft, maritime vessels, cargo, wood domestic and international mail, plant propagative material, livestock, pets and animal production. Different teams of APHIS scientists focused on different pathways and methodologies, depending on their area of focus, but all agreed that detailed information for making determinative rankings was limited – thus most risk rankings for pathways and species are qualitative.

The APHIS team developed over 200 recommendations to enhance biosecurity in the Micronesia Region. These recommendations are based on the specific risk assessments of each team and the observed state of biosecurity capabilities in the region. APHIS identifies a general lack of staffing, funding and biosecurity infrastructure in the region and recommends that sufficient funding be available at local and national levels and within the military to implement effective biosecurity region-wide. APHIS notes that user fees have been effectively used to generate funding for agriculture, wildlife disease and pest exclusion and recommends the legislative creation of a user fee structure similar to what is currently used by the USDA and the U.S. Department of Homeland Security.

APHIS draws particular attention to the need for sufficient numbers of well-trained staff and well-equipped biosecurity facilities and provides several specific recommendations to address these needs for both civilian and military attention. APHIS recommends several actions to enhance off-shore (pre-border) mitigation such as military pre-clearance facilities on Okinawa, weed risk assessments for importation of exotic plants and effective treatment of wood packing materials and imported timber products. Of particular note, APHIS recommends that military and civilian contracts include well-enforced requirements and provisions to minimize the risk of introduction of invasive species.

APHIS recommends a series of actions, including greater use of canine inspection teams and construction of necessary inspection, quarantine and wash-down facilities, to enhance point-of-entry biosecurity. APHIS also provides several recommendations in regards to the handling of cargo, mail and regulated garbage and export from and within the region which emphasize facilities, monitoring and inspection, and development of effective working relationships between regional, local, military and other U.S. Federal partners. Of highest priority is the need to maintain and enhance comprehensive brown treesnake (BTS) interdiction, control and eradication efforts on Guam. The BTS has caused massive direct and indirect impacts to the ecology and economy of Guam and APHIS provides numerous, specific recommendations, to both civilian and military sectors, to address this primary threat to the rest of Micronesia, Hawaii and other areas around the world.

In regards to regulations and compliance issues, APHIS recommends the military and civilian governments fully implement and take advantage of existing biosecurity guidelines and regulations. Specific to the military, APHIS suggests a revision of the DoN landscape plan to remove potentially invasive species from landscaping consideration and also recommends the development of a Memorandum of Understanding between DoD and all Micronesian countries to develop appropriate invasive species standard operating procedures for compliance when conducting activities in their respective jurisdictions. APHIS recommends outreach to pet stores, nurseries and landscaping companies to promote the adoption of a voluntary code of conduct to promote the use of native and non-invasive plants and to curtail smuggling of illegal, invasive pet species. APHIS also recommends that best management practices be developed for contractors and construction sites to prevent the introduction and spread of invasive plants and plant pests through their activities.

Several recommendations emphasize and support the development of invasive species training initiatives and outreach efforts to the public, military personnel and, particularly, to temporary workers who may come to the region as a result of the build-up. These efforts would raise general awareness of the potential harm that invasive species can cause and inform people of regulations, legal requirements and the consequences of violation. Outreach, effective communication and coordination are also critical components of successful monitoring and safeguarding efforts. APHIS recommends the development of an extensive biosecurity surveillance program for diseases, plants, plant pests and vertebrate invasive species that includes well developed processes and methodologies and incorporates expertise and capacity of other relevant entities in the region such as the Micronesia Challenge and other appropriate groups. APHIS highlights the need for background surveys to be conducted to establish baseline data for plants pests, invasive vertebrates, and diseases of livestock and wildlife throughout the region. This information would allow biosecurity plans to be refined and improved and should be completed as soon as possible.

Lastly, APHIS recommends a coordinated, centralized biosecurity effort for the region to maximize the effectiveness and efficiency of biosecurity activities, facilitate communication and cooperation between all public, private and military and other U.S. federal sectors involved and identify funding opportunities. Rapid or emergency response efforts should also be coordinated in a collaborative manner and APHIS recommends that rapid response capabilities as well as pre-export controls across the region should be improved – particularly at military and civilian airports and seaports on Guam, and the CNMI.

APHIS recommendations repeatedly emphasize the need for effective, meaningful collaboration amongst the various sectors, governments and partners to develop successful biosecurity efforts. Effective biosecurity requires sustained and managed funding and the flexibility to undergo regular reassessment and refinement as new information is obtained. APHIS asserts that the most cost-effective approach to protecting natural and economic resources in Micronesia is through implementing effective biosecurity measures before incursions or introductions occur.

# TAKE HOME MESSAGES

In Phase 1 of the MBP, over 50 federal and university scientists collaborated with dozens of local and regional scientists, government officials and invasive species experts to develop a comprehensive set of invasive species risk assessments, recommendations and best management practices that are unprecedented in their size and scope. While the different teams of scientists used a diversity of methods and approaches to their evaluations and recommendations, a number of common themes became clear. These "Take Home Messages" are summarized below:

- **Sufficient Staffing and Facilities**: The need for sufficient numbers of well-trained staff and well-provisioned facilities is critical for all biosecurity activities. In general, staffing and facilities in the region are inadequate for current levels of need, let alone for the levels required during and after the build-up.

- **Coordination and Collaboration are Critical**: Effective biosecurity for the region will require constant, open collaboration between all levels of government in Micronesia, DoD, other U.S. federal departments, the private sector, non-profit sector and regional organizations. Coordinated efforts amongst all partners will allow the region to more efficiently address critical issues such as:

    - Strategies to identify funding opportunities and secure commitments to ensure long-term, consistent funding and capacity for biosecurity efforts in the region.
    - Adoption of Memoranda of Agreement between nations and other partners to harmonize and/or establish plans, command structures, roles and responsibilities in regards to specific biosecurity issues.
    - Establishment of clear policies and required best management practices to address a variety of marine, terrestrial and freshwater invasive species concerns.
    - Development and/or improvement of regionally coordinated efforts on:
        - Early detection and rapid response to invasive species.
        - Outreach and education to both civilian and military sectors on invasive species issues and biosecurity.

- **Information Needs**: New research and repetitive, systematic surveys are needed throughout the region to advance the science behind biosecurity and to establish baseline data on invasive species that is accurate, current and reflects the dynamics of changing situations. . Accurate and current baseline data together with other pertinent information (such as economic analyses and societal and cultural valuation of invasive species impacts) will allow for higher quality risk assessments that will inform the development of more effective and efficient biosecurity measures.

- **A Flexible, Living Document:** The MBP must be frequently revised and updated to allow incorporation of new information (such as invasive species baseline data), technologies and methodologies that will increase the effectiveness and efficiency of biosecurity efforts.

NISC has been honored to be part of this worth-while effort. We thank our colleagues throughout Micronesia, the U.S. federal government and in the broader Pacific for their hard work and dedication in producing the MBP – an effort that will benefit all of Micronesia and set an example for other regions of the world.

Special attention needs to be brought to the role of the Micronesian Chief Executives and DoN in enabling this effort. The Micronesian Chief Executives have been proponents of the development of the MBP from its inception and publicly endorsed the effort and instructed their staffs to fully participate in its development and implementation in Resolution 17-7 of the 17$^{th}$ Micronesian Chief Executives' Summit. The development of the MBP also directly supports the "Green Guam" and "One Guam" pillars of the "four pillars that will shape the (build-up) strategy" – as stated by Undersecretary of the Navy Robert Work in 2011 and is prima facie evidence of DoN engaging in a meaningful way with regional partners to address issues of common concern. In supporting this effort and by acknowledging the critical role of cooperative relationships, the Micronesian Chief Executives and DoN have attempted to *proactively* address the invasive species implications of the build-up, not just for Guam and the CNMI where the build-up will happen, but for the entire region.

# Regional Biosecurity Plan for Micronesia and Hawaii Freshwater Risk Assessment

The freshwater risk assessment is composed of edited elements of three reports prepared for DoN as part of the overall MBP development strategy. These reports in their entirety can be accessed at the DoN supported website.

The original reports titles are as follows:

- Assessing the risk posed to Micronesia by invasive aquatic weeds
- Biosecurity plan for freshwater invasive aquatic plants in Micronesia
- Risk analysis and management alternatives for the prevention and mitigation of nonindigenous fishes and other aquatic macrofauna in freshwater habitats of Micronesia

## Introduction

Invasive alien species (IAS) are a significant threat to the integrity of freshwater systems throughout the world. Some of these threats include the alteration of ecosystem services, the loss of aquatic biodiversity, and the degradation of water quality for the human populations that rely on those waters. Identifying the pathways and vectors by which aquatic IAS may be introduced, understanding the factors that may contribute to the spread and establishment of IAS taxa is critically important to preventing the introduction of IAS and mitigating their ecological effects and ensuring that appropriate biosecurity measures are in place for the islands of Micronesia and the state of Hawaii in order to protect these jurisdictions from the negative cross-cutting effects of IAS.

Given their relative isolation, the islands of Micronesia and Hawaii may be particularly sensitive to the introduction of aquatic IAS taxa. Many of these islands are already host to a variety of non-indigenous fish, invertebrates, and macrophytes. To address these concerns, the Department of Defense has sponsored the development of risk assessments and management alternatives to minimize the introduction and spread of aquatic IAS throughout Micronesia and Hawaii.

This volume of the Micronesian Biosecurity Plan includes (1) risk assessments for invasive aquatic macrofauna and (2) management strategies to prevent the importation and spread of IAS between the different jurisdictions. The aquatic macrofauna risk assessment and management alternatives were developed by the U.S. Geological Survey (Section 1). The aquatic macrophyte risk assessment and biosecurity plan was developed by Portland State University (Section II) in partnership with the New Zealand National Institute of Water and Atmospheric Research, Ltd. (NIWA).

**Prepared with cooperation and funding by the U.S. Department of the Navy**

# Risk Analysis and Management Alternatives for the Prevention and Mitigation of Nonindigenous Fishes and other Aquatic Macrofauna in Freshwater Habitats of Micronesia

From an original document prepared by Stephen J. Walsh, Leo G. Nico, Mark W. Miller, and Ronald A. Englund

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|---|---|---|
| | Length | |
| centimeter (cm) | 0.3937 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| | Area | |
| square meter ($m^2$) | 0.0002471 | acre |
| hectare (ha) | 2.471 | acre |
| square kilometer ($km^2$) | 247.1 | acre |
| square meter ($m^2$) | 10.76 | square foot ($ft^2$) |
| hectare (ha) | 0.003861 | square mile ($mi^2$) |
| square kilometer ($km^2$) | 0.3861 | square mile ($mi^2$) |
| | Volume | |
| cubic meter ($m^3$) | 0.0002642 | million gallons (Mgal) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

# Risk Analysis and Management Alternatives for the Prevention and Mitigation of Nonindigenous Fishes and other Aquatic Macrofauna in Freshwater Habitats of Micronesia

By Stephen J. Walsh[1], Leo G. Nico[1], Mark W. Miller[1], and Ronald A. Englund[2]

## Executive Summary

This report provides an assessment of potential risks posed by the introduction and spread of nonindigenous freshwater organisms in Micronesia. The basis for this study is an anticipated increase of U.S. military and civilian activities on and around Guam and the Commonwealth of the Northern Mariana Islands. The focus of this effort is on invasive or potentially invasive freshwater animals, mainly fishes, and the pathways by which these aquatic organisms are introduced to regions outside their native ranges. The risk assessment analysis and accompanying management alternatives are provided as part of a biosecurity plan for the entire Micronesian region. The emphasis is on the islands of Guam, Commonwealth of the Northern Mariana Islands, Federated States of Micronesia (specifically, Chuuk, Kosrae, Pohnpei, and Yap), and Palau, because these are the largest islands and those with the greatest extent of freshwater resources.

The objectives of this study were to (1) summarize available information on native and nonindigenous macrofauna of freshwater systems in Micronesia; (2) identify and evaluate pathways of introduction and assess the risk of introducing nonindigenous freshwater animals into new environments of Micronesia; (3) identify those aquatic and semiaquatic animals that have the potential to become widely established or invasive in inland waters of Micronesia, and; (4) provide management options with the goals of preventing or reducing the likelihood of introduction and spread of freshwater animals into and among the islands of Micronesia as well as mitigating risks. Emphasis is placed on freshwater fishes, because more is known about this group than the others, although information is also summarized for selected non-native taxa of other groups, mostly aquatic or semiaquatic mollusks, crustaceans, amphibians, and reptiles.

Micronesia is a heterogenous subregion of Oceania, comprising thousands of small tropical islands scattered across a vast expanse of the western Pacific Ocean, from the Mariana Islands and Palau in the west to Kiribati in the east. Micronesian islands and islets are extraordinarily diverse and complex in terms of geography, physiography, geology and biology. Although individual islands in Micronesia are surrounded by ocean, many contain a diverse array of natural freshwater habitats. Whether permanent freshwater habitats are present, and, if present, their type, diversity, and extent depends on a wide range of factors, including island location and size, geologic history, and physiography (e.g., elevation and topography). These factors and

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other characteristics vary widely among the many islands and islands groups of Micronesia and the Pacific. Many islands are quite distinctive in terms of their geomorphology and aquatic habitats. In general, larger islands, especially those with the greatest topographic relief, have more extensive and diverse inland freshwater ecosystems that include an array of streams, springs, wetlands, and natural lakes. Artificial freshwater habitats are also common, especially on islands populated by humans, and typically consist of reservoirs, ponds, ditches and small canals.

Freshwater habitats on Micronesian islands support moderately diverse and unique native biological communities. Although the total number of native freshwater species on any one island group is relatively low in comparison to continental faunas, native aquatic animals present are extremely important from a global perspective. This is due to a great degree of endemism in Micronesia—many species and community assemblages that are found nowhere else in the world. The most prominent freshwater animals are fishes and macroinvertebrates, and most of the native fishes, crustaceans, and aquatic mollusks (gastropods) are amphidromous species—that is, they are derived from marine ancestors and have a unique life history in which adults spawn in rivers and streams, eggs or larvae drift to the ocean, and juveniles then return to fresh water to complete their life cycle.

Invasive and other nonindigenous aquatic species have changed or otherwise affected all or most Pacific islands containing permanent freshwater habitats. Indeed, a wide variety and large number of nonindigenous fishes and various other nonindigenous aquatic animals have been introduced to freshwater habitats of Micronesia and other islands of Oceania. As a result, nonindigenous freshwater species are common on most islands in the region that have freshwater environments. Pathways are defined here as the general route or activity by which a species can be introduced into a new locale whereas vectors are considered to be the specific mechanisms or modes of introduction. The pathways and mechanisms by which these nonindigenous organisms were introduced are varied; some were brought intentionally by humans, and many others arrived accidentally. Guam, in particular, has more nonindigenous freshwater fishes and other aquatic fauna than any other island in Micronesia and is second only to Hawaii among islands in the tropical Pacific in this regard. However, all of the large islands have been affected to some degree by the introduction of freshwater species.

The risk assessment presented herein is based on a quantitative analysis of fish introductions to inland waters of Guam and Hawaii. This data set is used because it is derived from historical and current information that is far more complete and includes records of more nonindigenous aquatic taxa than any other group of islands in the tropical Pacific. The data used in the risk assessment are based on a total of 80 species or taxa, 49 (61%) of which are known to be established (that is, have reproducing populations) on Hawaii, Guam, or both. One dependent variable (prior establishment success) and 14 independent variables, including factors that relate to propagule pressure, life-history attributes, and physiological tolerances, were used to develop 21 *a priori* and 8 *post hoc* frequentist (logistic) models to determine probabilities of establishment success. The best model derived from this analysis included three primary factors used to predict establishment success: (1) a random family (taxonomic) effect; (2) prior invasion success on tropical islands or island groups globally, and; (3) hypoxia tolerance (i.e., tolerance to low dissolved oxygen using a categorical variable with three possible states).

Results of the risk assessment have utility in that the models can be used to assign probabilities of establishment success of species or taxa not currently established in Micronesia. For instance, the Guam Division of Aquatic and Wildlife Resources (DAWR) maintains a white (or "clean") list of aquatic species (freshwater and marine fishes, invertebrates, and plants) that are permitted for legal importation. Our risk assessment model could be used to evaluate relative risk for species that are currently on Guam's white list, or species that might be under consideration in the future. Although the white list is a regulatory tool that DAWR uses to manage for potential introductions of invasive species (by limiting imports), there is currently no legislation that prohibits the possession of species not on the white list, including species considered potentially invasive or injurious. Establishment pathways of freshwater species were evaluated in our risk assessment, and are also addressed in the section on management alternatives. Although all pathways pose certain risks, the general pathways identified as posing the greatest risk for introductions (and spread) of freshwater species in Micronesia include: (1) the aquarium trade and commerce in ornamental species; (2) aquaculture, and; (3) the live-food trade.

As an objective, policy-neutral, science-based agency, the USGS has no management or regulatory authority. Therefore, the USGS refrains from making recommendations that target specific management or policy actions, and terminology such as "best management practice" or "BMP" is not used. Herein, management alternatives are provided with an implicit understanding that all options have not been thoroughly vetted and strategic actions may be warranted and modified over time as new information becomes available. Many existing sources provide baseline information on strategies for mitigating deleterious ecological or socioeconomic effects of invasive species; the information provided in this report is based on sources considered reliable.

Management alternatives for the prevention and mitigation of non-native freshwater species in Micronesia involve a variety of approaches and include, but are not limited to, the following:

- Continued monitoring of imports
- Improved inspection and detection programs
- Improved training of inspectors
- Improved knowledge about propagule pressure using surveys and other information-gathering approaches
- Expanded education and outreach programs
- Independent scientific review of DAWR white list of permitted aquatic species
- Improved management of aquaculture facilities
- Improved monitoring/detection of commodities in the live-food market
- Additional biological surveys
- Establishing robust monitoring programs based on appropriate statistical approaches that incorporate detectability and occupancy models
- Establishing a rapid response strategy and contingency plan for new introductions
- Additional scientific research and data compilation to assess more fully relative risk based on multiple factors (e.g., pathways, taxonomic groups, biological attributes) and data gaps

Implementation of management options should focus foremost on prevention and remain flexible enough to deal with changes in technology, transportation, and world markets. In particular, vigilance is needed to identify existing high-risk pathways or vectors and identify potential future pathways and vectors. For example, a wide variety of potentially invasive freshwater animals are currently available worldwide for purchase over the Internet and there is ample and easy opportunity for a person living in Guam or elsewhere in Micronesia to obtain an aquatic animal not previously introduced to the island, including organisms whose import is illegal. Use of private shippers increases the possibility that such an import might proceed undetected by custom agents. Closing the loophole of such high-risk factors may require substantial modifications to existing practices, policies, or management structure and procedures. If introduction of a harmful non-native species is not successfully prevented, then eradication or containment efforts may result, both of which are strategies that require intensive, costly planning and logistics at many levels. Improved biosecurity for non-native freshwater species in Guam and the Commonwealth of the Northern Mariana Islands (CNMI), in particular, will require cooperation and coordination between the U.S. military, various island nations and states, and civilian sectors.

## Overview

The purpose of this report is to provide an assessment of potential risks posed by the introduction and spread of nonindigenous freshwater organisms in Micronesia. Increased threats posed by nonindigenous species may accompany increased U.S. military and civilian activities anticipated in and around Guam and the Commonwealth of the Northern Mariana Islands. This report focuses on invasive or potentially invasive freshwater animals, mainly fishes and selected amphibians, reptiles, and macroinvertebrates, and the pathways by which these aquatic organisms are introduced to regions outside their native ranges. Included are mitigation measures to prevent or reduce the likelihood of introduction and spread of freshwater animals into and among the islands of Micronesia.

This report constitutes a component of a broader Micronesian Biosecurity Plan (MBP) that addresses a variety of non-native organisms, including terrestrial and aquatic (marine and freshwater) animals and plants, as well as parasites and pathogens. The MBP includes comprehensive information derived from risk assessments and review of existing conditions as provided by multidisciplinary teams of biologists and other scientists representing various agencies and institutions (USDA-APHIS 2010; ABRPI 2011; Zabin et al. 2011).

Micronesia is a heterogenous subregion of Oceania, comprising thousands of small tropical islands scattered across a wide expanse of the western Pacific Ocean, from the Mariana Islands and Palau in the west to Kiribati in the east. The more than 3,000 Micronesian islands and islets are extraordinarily diverse and complex in terms of geography, physiography, geology and biotas. All Micronesian islands combined have a total surface or land area that is estimated to cover anywhere from about 2,700 to 3,227 $km^2$ (1,042 to 1,246 $mi^2$) (Crombie and Pregill 1999; Steadman 2006). Many of the individual island groups are relatively remote and separated by great distances from their nearest neighbors. Although most of the islands are far from continental land masses, a few are relatively close to the large island of New Guinea. Because of its size and complex geography, the nomenclature of Micronesian islands and island groups, including that of their political alliances, can be confusing and cumbersome.

## Background

Introductions of non-native species to the islands of Oceania began with the earliest human inhabitants. Over the past several hundred years, and especially over the past few decades, the numbers and kinds of different nonindigenous species introduced have increased substantially. Although the introduction of freshwater aquatic animals to Pacific island habitats is relatively recent in comparison to the introduction of many non-native plants and terrestrial animals, over recent decades there have been multiple introductions and spread of freshwater species throughout islands of Oceania. Taxonomic groups introduced into freshwater habitats include fishes, amphibians, reptiles, and invertebrates (primarily crustaceans and mollusks). Current knowledge about the status of nonindigenous species in freshwater habitats varies with island or island group in Micronesia, and to a large extent, corresponds to degree of study by biologists or survey efforts by government agencies and nongovernmental organizations. In general, the most complete information exists about freshwater biotas for those islands with large human populations and extensive freshwater habitats, two characteristics that are closely linked. Thus, Guam, the Commonwealth of the Northern Mariana Islands (especially Saipan), Palau (Babeldaob and Koror), and the large, high islands of the Federated States of Micronesia (Pohnpei and Kosrae) have been the most intensively explored. Nevertheless, nearly all islands are considered to be inadequately surveyed.

A number of authors have assembled lists of what they consider to be the most detrimental invasive species—those introduced organisms that commonly are introduced, become established, and thrive and dominate in new places. For example, Lowe et al. (2004) produced a list of “100 of the World’s Worst Invasive Alien Species.” Of the eight fish species listed, seven have been introduced to islands in the Pacific. Similarly, Helfman (2007) provided a list of ten freshwater fish taxa whose introductions were considered to be especially controversial, largely due to their resulting ecological or economic impacts (Table 1). At least eight of the taxa on Helfman’s list have been introduced into Micronesia, and most are established there; additionally, a moderate number of other non-native fish species have been introduced and are considered established. To a lesser extent, other non-native freshwater animals have been introduced. However, there are notable examples of highly successful and even invasive and injurious aquatic or semiaquatic species of other taxonomic groups. For example, Guam is now host to a moderate number of frogs (Christy et al. 2007a, b), including the widespread and locally abundant cane toad, *Rhinella marina* (=*Bufo marinus*). In addition, the red-eared slider (*Trachemys scripta elegans*) is a freshwater turtle that has been introduced worldwide (Kraus 2009a), and wild populations are documented as established in Guam (Leberer 2003).

Table 1. Selected controversial freshwater fish species introduced in different regions of the world, based on Helfman (2007) and references therein. [Numbers of countries and states where established considered herein to be general approximations]

| Species | Number of countries where established | Number of U.S. states where established | Native distribution | Purpose of introduction[a] |
|---|---|---|---|---|
| *Cyprinus carpio*, common carp | 49 | 49 | Eurasia | Food, ornamental |
| *Carassius auratus*, goldfish | >40 | 49 | East Asia | Ornamental |
| *Ctenopharyngodon idella*, grass carp | ?[b] | 45 | East Asia | Biocontrol |
| *Oncorhynchus mykiss*, rainbow trout | 56 | 48 | North America | Sportfishing, food |
| *Gambusia affinis, G. holbrooki*, mosquitofish | 67 | 35 | North America | Biocontrol |
| *Poecilia reticulata*, guppy | 34 | 15 | South America | Ornamental, biocontrol |
| *Micropterus salmoides*, largemouth bass | 53 | 43 | North America | Sportfishing |
| *Lates niloticus*, Nile perch | 3 | 1 | East Africa | Food |
| Tilapiine cichlids (many species) | 94 | 13 | Africa | Food, biocontrol |
| *Cichla* spp., peacock cichlids | 6 | 2 | South America | Sportfishing |

[a] Primary purpose(s) of introduction as provided by Helfman (2007), but the authors are aware of situations where some of these species were introduced for additional reasons.

[b] Helfman (2007) gives number of countries as nine, considered here to be a significant underestimate.

## Goals and Objectives

The principal objectives of this study were to (1) summarize available information about native and non-native macrofaunas of freshwater systems in Micronesia, with emphasis on Guam; (2) identify and evaluate pathways of introduction and assess the risk of introducing nonindigenous freshwater animals into new environments of Micronesia; (3) identify those freshwater species or groups that have the potential to become widely established or invasive in Micronesia, and; (4) provide management options for preventing unwanted introductions and for mitigating risks. Emphasis is placed on freshwater fishes, because more is known about this group than the other faunal groups mentioned in this report. Moreover, assessment and management practices for freshwater fishes have similar applicability to other groups of aquatic and some semiaquatic animals, including vertebrates and invertebrates.

## Environmental Setting: Inland Aquatic Environments

The individual islands of Micronesia (Fig. 1) are surrounded extensively by ocean, yet many contain a diverse array of natural freshwater habitats. The presence or lack of freshwater habitats, and, if present, their type, diversity, and extent depend on a wide range of factors, including island location and size, geologic history, and physiography (e.g., elevation and topography). These factors and other characteristics vary widely among the many islands and islands groups of Micronesia and the Pacific. Steadman (2006) recognized at least seven different types of Pacific islands: (1) active volcanic islands; (2) eroded volcanic islands (e.g., Babeldaob in Palau); (3) raised limestone islands; (4) atolls; (5) "almost atoll" islands; (6) sand cays or keys; and (7) composite islands (i.e., consisting of multiple types of exposed bedrock, such as Guam, which contains outcrops of limestone and volcanic rock).

In general, surficial freshwater habitats are few in number or absent on atolls and sand cays, as well as on many of the very small, low-elevation islands and islets. In contrast, larger islands, especially those with the greatest topographic relief, typically have more extensive and diverse inland freshwater habitats that include, depending on the particular island, small and large streams, springs, wetlands, and natural lakes. Artificial freshwater habitats are also common, especially on islands populated by humans, and typically consist of reservoirs, ponds, ditches and small canals. Most natural freshwater systems on Micronesian islands are linked to the ocean either directly or through estuarine or other brackish-water transition zones. Because of the association between fresh and salt water and the general isolation of the islands from continental areas, native fishes and invertebrates present in freshwater environments of these islands have evolved from marine ancestors, and nearly all depend on marine or brackish-water habitats for certain critical parts of their life cycle; for example, for food resources, nursery habitats, or spawning (Ford and Kinzie 1982).

This report focuses on a few of the major islands and island groups of Micronesia, mainly those with substantial freshwater resources: Guam, the Commonwealth of the Northern Mariana Islands (CNMI), the Federated States of Micronesia (FSM), and Palau. Brief descriptions of these select islands/island groups and their inland freshwater environments are presented in following sections. Additional information on inland aquatic environments of Micronesia is available from the Water and Environmental Research Institute of the Western Pacific (WERI), University of Guam (*http://www.weriguam.org/*), which conducts extensive research and monitoring of aquatic resources in Guam and throughout Micronesia. The WERI, in collaboration with other organizations and agencies, has produced or reprinted many important documents about the geology and freshwater resources of Micronesia. Most of these documents are available on the institute’s web site and are the source of much of the information presented here.

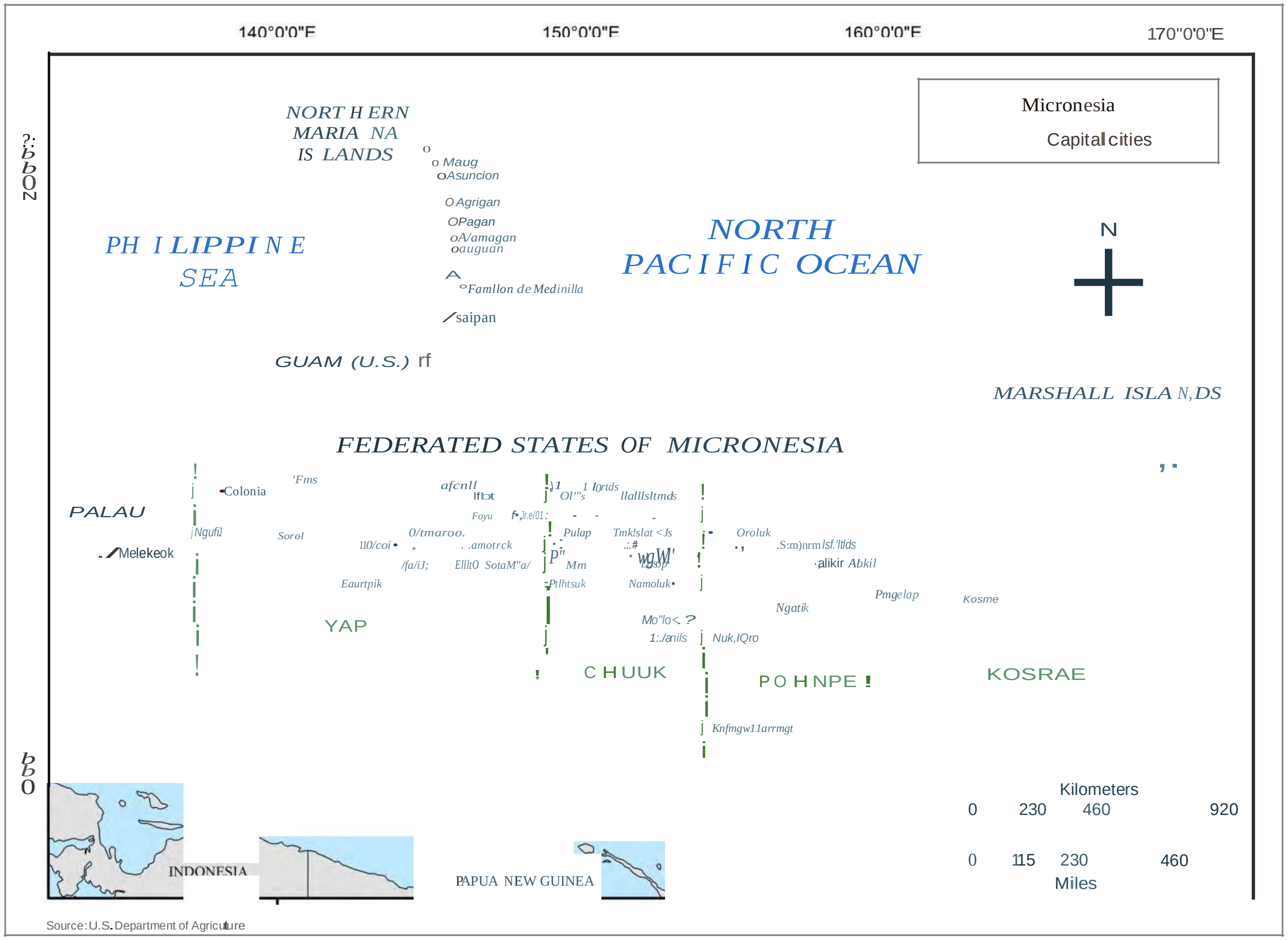


Figure 1. Map of Micronesia and political sovereignties.

## Guam

### Background

The climate of Guam is warm tropical, with air temperatures that are relatively uniform throughout the year; annual average temperature is about 26°C (79°F) and monthly means range from about 24° to 27°C (76° to 80°F) (*http://ns.gov.gu/climate.html*; Yeung 2005). Relative humidity ranges from about 65% during the day to 100% at night. Rainfall is the source of all fresh water in Guam and averages about 216-292 cm (85-115 inches) per year (Gingerich 2003). Rainfall recording stations differ in annual total by as much as 76 cm (30 inches) due to the island's orography and southern mountainous region. More rainfall occurs in the southern highlands in comparison to the central and coastal lowlands. Most (about 70%) of the rainfall for the entire island occurs during the wet season, from July through November or December; the pronounced dry season typically extends from January through May (Ward et al. 1965). Typhoons have historically resulted in episodic and prolonged rainfall events. In contrast, droughts in Guam are common and may be severe.

Guam has been the subject of extensive geologic and hydrogeologic investigation. The primary reference on the geology of Guam is that of Tracey et al. (1964). The first comprehensive hydrologic study of the island was by Ward et al. (1965). More recent synoptic publications that provide additional summaries of hydrogeologic research and syntheses of information about Guam's karstic features include those of Mink and Vacher (1997), Siegrist and Randall (1992), Taboroši (2000), Mylroie et al. (1999; 2001), and Taboroši et al. (2004, 2005). Karst topography is a landscape shaped by the dissolution of soluable bedrock, usually carbonate rock such as limestone or dolomite. The porous conditions commonly results in subterranean drainages with limited surface water. Guam's karst features are typically described in the framework of the Carbonate Island Karst Model (CIKM), a theoretical model that characterizes unique karstic terrain of relatively young limestones of small islands (Mylroie and Carew 1995; Mylroie and Jenson 2000).

Volcanic rock forms the foundation of Guam and is exposed over about 35% of the island; overlying this rock is limestone that is exposed over about 60% of the island. Seven major geologic units are represented, six of which lie in the southern half of the island (Fig. 2). A major fault line that extends approximately from Pago Bay on the east coast to Asan on the west coast divides the island into two basic physiographic provinces (Tracey et al. 1964; Kingston 2004; Taboroši et al. 2005). To the north of this fault is a limestone plateau consisting of carbonate island karst (eogenetic karst) that is broken by two volcanic intrusions (Tracey et al. 1964; Gingerich 2003; Taboroši et al. 2005). This limestone plateau lacks rivers or streams, but is porous, allowing percolation of rain water into an underlying freshwater-lens system that lies above salt and brackish water (Gingerich 2003; Kingston 2004). Groundwater resources of the northern plateau provide the vast majority of freshwater supply for human use on the island. Consequently, there have been exhaustive hydrologic, geologic, and chemical studies of this region (Mink and Vacher 1997). The southern half of the island consists of seven primary physiographic provinces that can be classified into three categories: lowlands, limestone plateau, and volcanic uplands (Fig. 3).

The southern half of Guam is mountainous (Fig. 4) with a peak elevation of 406 m (1,332 ft) on Mount Lamlam. The southern mountains consist of exposed volcanic rock and soils that are relatively impervious to groundwater percolation, and karst features that are generally porous and similar to continental karst (Tracey et al. 1964; Taboroši et al. 2005).

## Freshwater Habitats of Guam

Due to its more mountainous terrain, fewer exposed karst features, and wetter climate, southern Guam has many more freshwater habitats than the northern part of the island (Table 2; Appendix 1). The southern half includes about a hundred named rivers and streams (Fig. 5), 46 of which drain into the ocean (Best and Davidson 1981; DAWR 2006). The largest river system in Guam is the Talofofo River, draining an area of approximately 73 $km^2$ (28 $mi^2$). The river originates on the eastern slopes of Mount Lamlam in southwestern Guam and flows to the northeast into the sea at Talofofo Bay. Nine of Guam's 46 rivers that drain into the ocean have true estuarine zones (DAWR 2006). A mountain ridge that extends along the western coast defines many of the drainages. With many small catchments draining directly to the ocean, watersheds of the island are grouped into 14 larger units (Fig. 5). Some of Guam's lotic systems are intermittent, with continuous flow only during periods of heavy rainfall. Extensive online spatial data and synoptic information about the natural resources of southern Guam are available on the WERI website (*http://www.hydroguam.net/watersheds-overview.php*).

Second in importance to rivers and streams in terms of their contribution to the total fresh water in Guam are habitats formed by springs, vegetated wetlands (both natural and artificial), impoundments, canals, and water-retention basins. Although dated, the review by Best (1981) provides a bibliography of inland aquatic resources of the Marianas archipelago, including documents relevant to the freshwater resources of Guam. Ellison (2009) gave a general summary of the wetland resources on islands throughout the western Pacific region. Agana Springs and Agana Swamp are two of Guam's best known spring and wetland habitats and are sites where nonindigenous aquatic species have been introduced. Hydrology of the downstream reaches of the Agana River were altered by efforts to drain the swamp as well as groundwater pumping (Randall et al. 1974); today, these sites are disturbed from encroaching development, runoff of sediments and contaminants, and invasive species.

The largest reservoir in Guam is Fena Reservoir (Fig. 5), a water-supply impoundment constructed for the U.S. Navy in 1950-1951, with a drainage area of approximately 15 $km^2$ (5.8 $mi^2$) and surface-water area of 78 hectares (193 acres) (LaBaugh 1985). Fena Reservoir is situated on the Maagas River, a headwater tributary of the Talofofo River. The reservoir has been the site of introduction of various nonindigenous plants and animals (e.g., Brock and Takata 1956; DAWR 2006), some of which persist and others that never became established. In the past consideration was given to developing additional water-supply reservoirs, especially the large basins of the Ugum, Ylig, Pago, and Inarajan (USACE 1979); no effort was made herein to ascertain the current status of proposed water-development projects in Guam. It is worth noting, however, that water impoundments and reservoirs are particularly susceptible to the introduction and establishment of nuisance aquatic species. Furthermore, these systems disrupt the flow regimes for native instream communities both above and below the impoundment. Thus, any planned water development projects should consider ways to mitigate against potential introductions and maintain the ecological integrity of the native instream communities.

A number of aquaculture facilities in Guam, currently inactive and active, have ponds that have also been sites where nonindigenous aquatic species have been introduced (B. Tibbatts, DAWR, oral commun., 2010). Additionally, a few golf courses have artificial impoundments that are inhabited by nonindigenous species.

Table 2. Freshwater habitats of Guam (DAWR 2006).

| Habitat type | Location | Percentage of area | Relative condition | Needs |
|---|---|---|---|---|
| Freshwater swamps | Edges of marshes, along river courses, wet depressions in forests | 0.06 | Unknown | • Implement current management plans/laws<br>• Control invasive species of vegetation and animals |
| Freshwater marshes | Common from central to southern Guam | 0.29 | Stable | • Implement current management plans/laws<br>• Control invasive species of vegetation<br>• Control BTS |
| Reservoirs | Widely through southern Guam | 0.01 | Unknown | • Implement current management plans/laws<br>• Control invasive species of vegetation |
| Mangroves | Southern Guam | 0.14 | Stable | • Implement current management plans/laws<br>• Control invasive species of vegetation<br>• Prevent further habitat loss |
| Rivers | Southern Guam | 0.13 | Unknown | • Implement current management plans/laws<br>• Reduce sedimentation<br>• Control invasive species of vegetation |

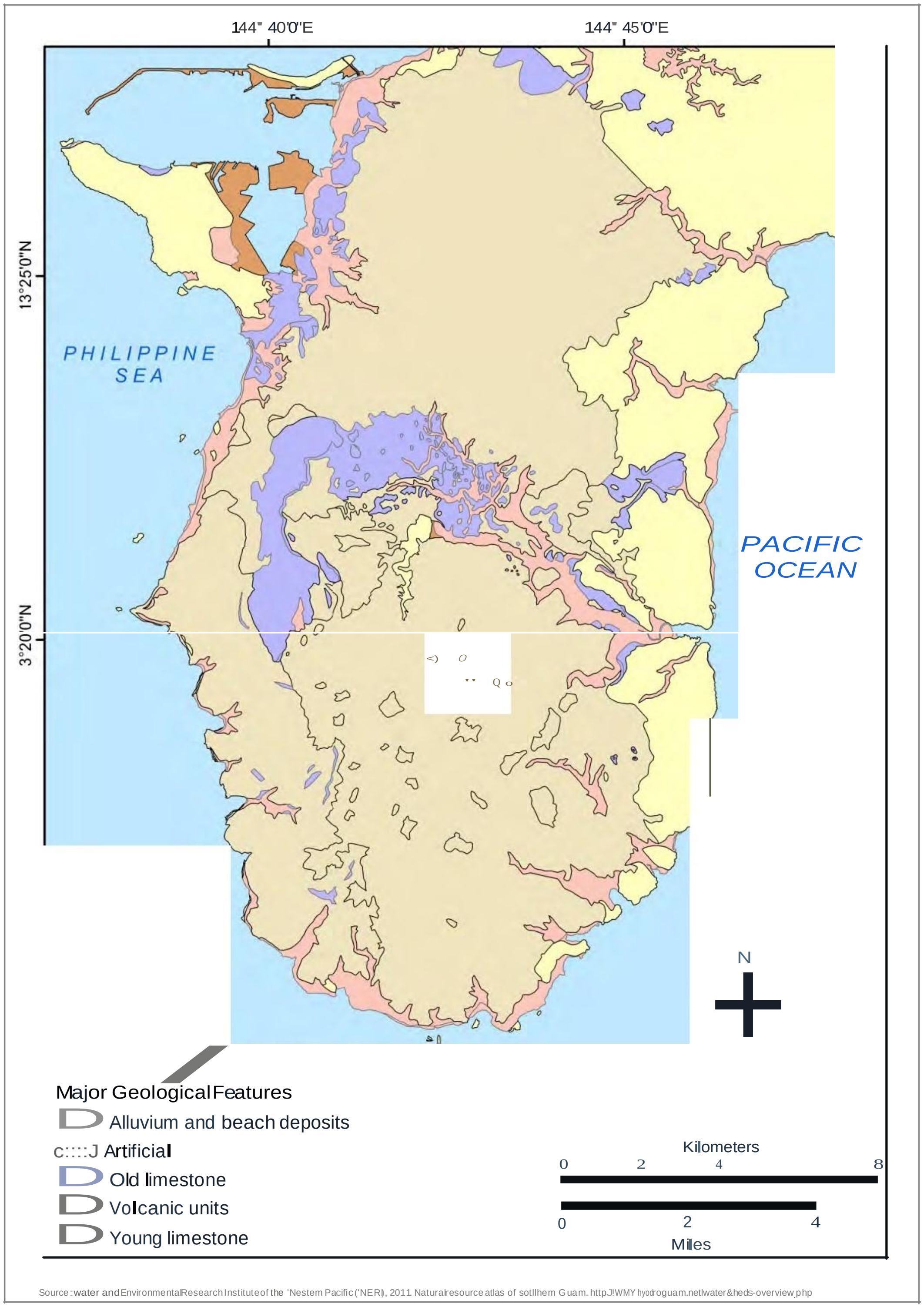


Figure 2. Major geological features of southern Guam (modified from WERI 2011).

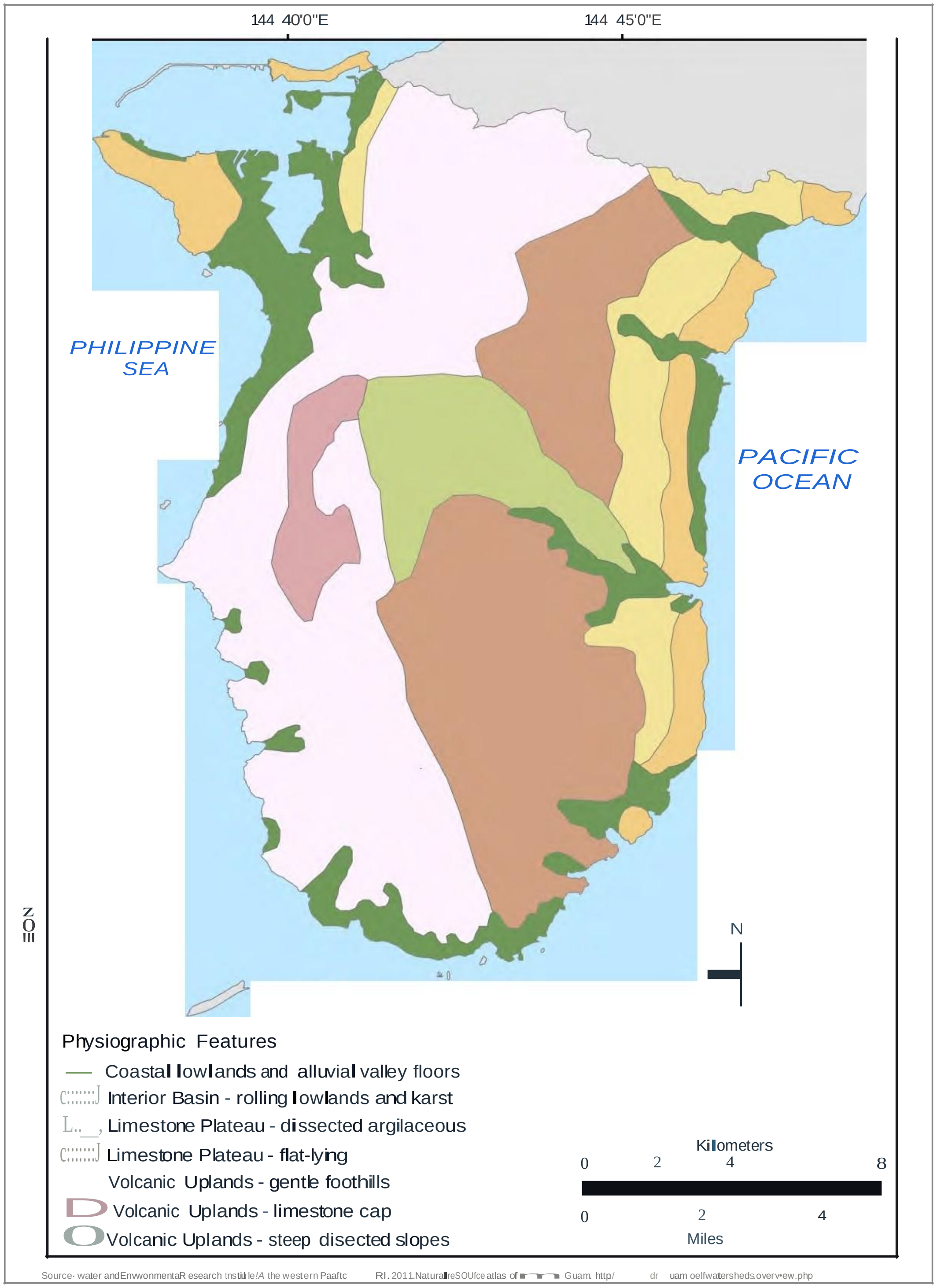


Figure 3. Physiographic provinces of southern Guam (modified from WERI 2011)

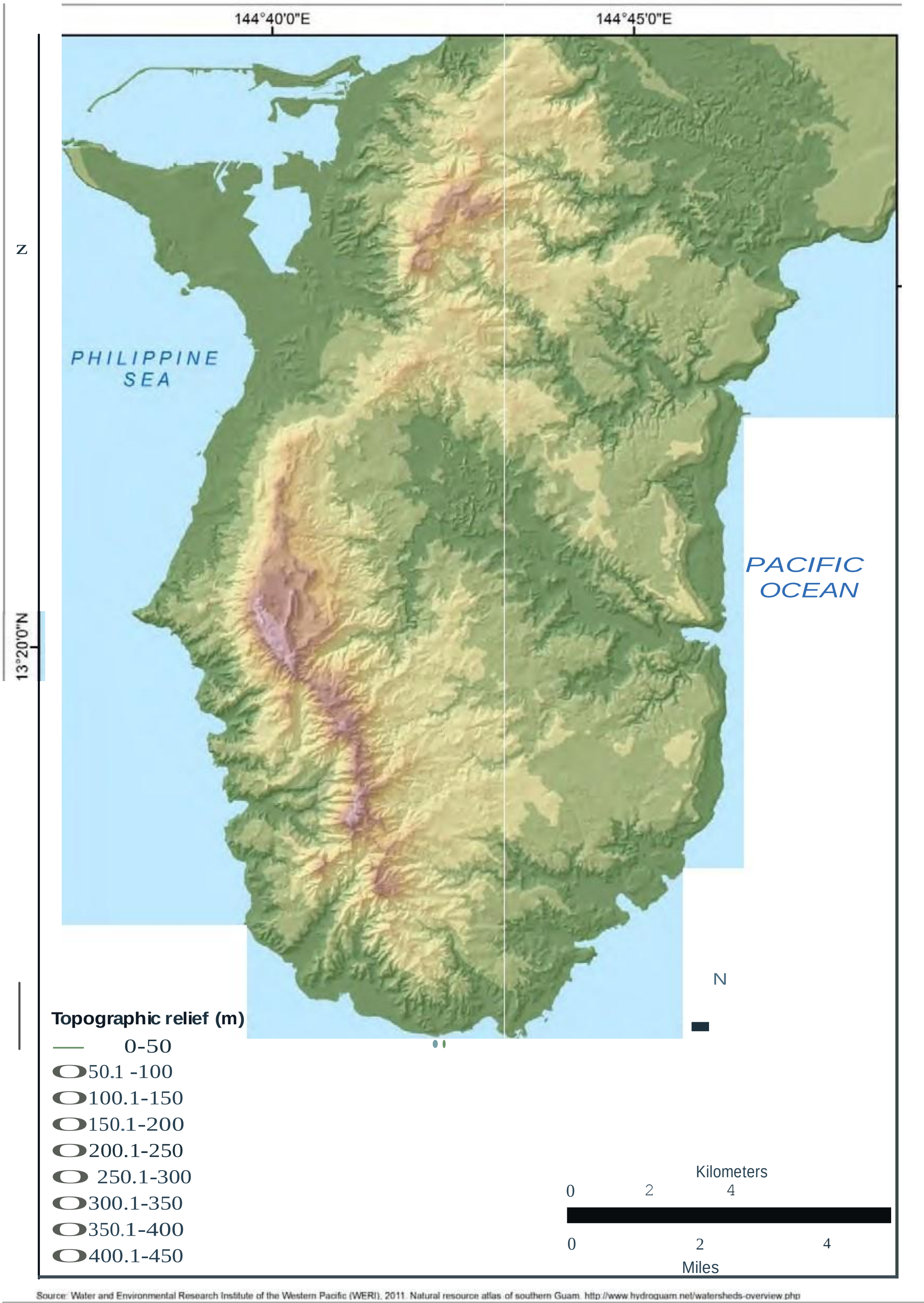


**Figure 4. Topographic relief of southern Guam (modified from WERI 2011).**

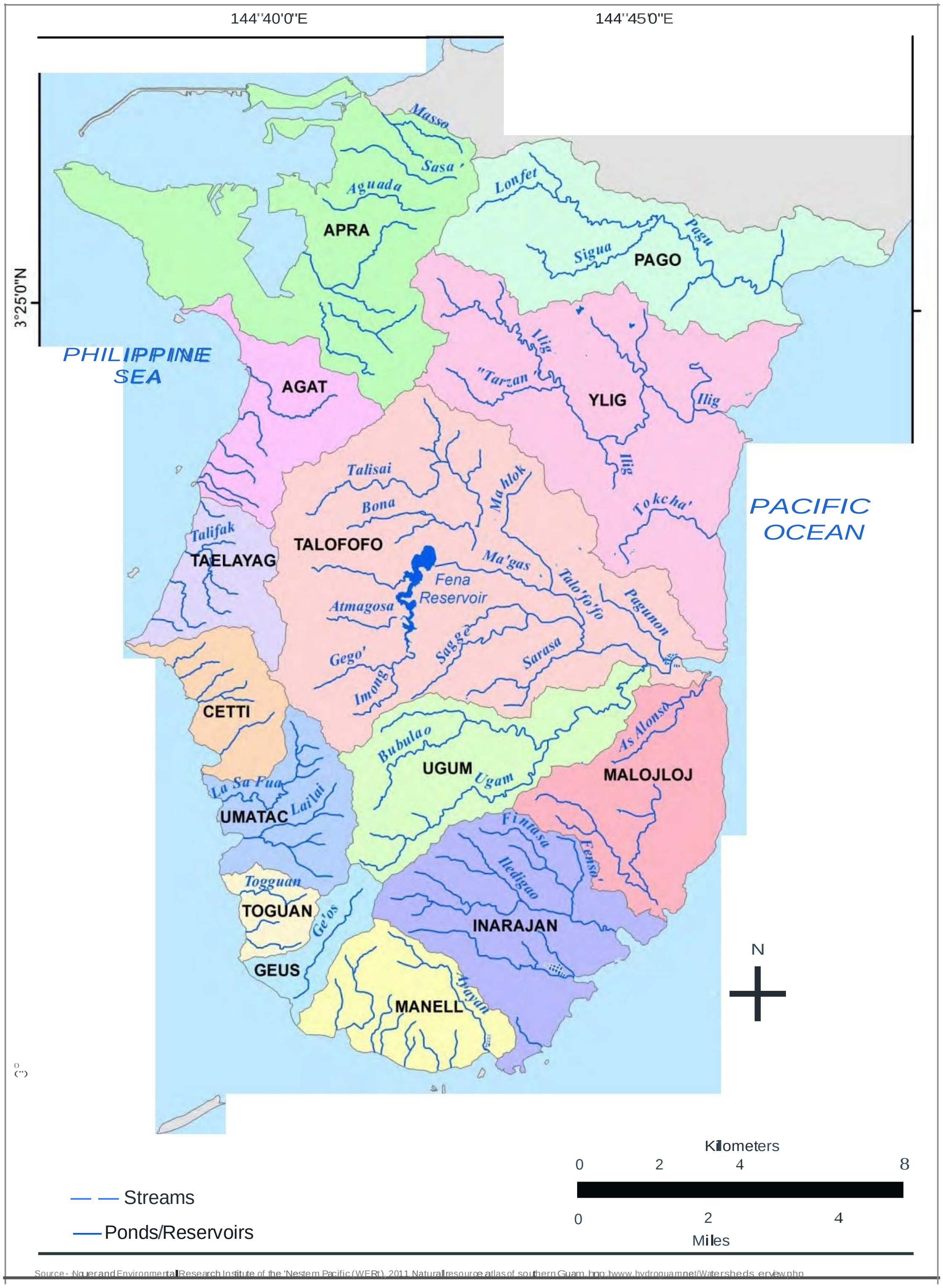


Figure 5. Streams and watersheds of southern Guam.

## Commonwealth of the Northern Mariana Islands

### Background

Surface-freshwater resources in the CNMI are limited primarily to the islands of Saipan and Rota. The only other island of CNMI with freshwater habitats of significance is Tinian.

### Freshwater Habitats of the CNMI

#### Saipan

Although Saipan has no continuously perennial streams (permanently flowing to the ocean), several semi-permanent pools and perennially flowing stream sections support freshwater aquatic biota (Best and Davidson 1981). Additionally, there are several important wetlands situated largely along the Western Coastal Plain, the most significant of which is Lake Susupe, a mixed brackish and freshwater wetland approximately 17 hectares (42 acres) in surface-water extent during normal water levels; this system consists of a series of intermittent potholes that result in lake fluctuations depending on stage, but the wetland is perennial (Carruth 2003; McKagan et al. 2009). Lake Susupe and the large contiguous reed marsh and swamp on the western coastal plain of Saipan comprise over 60% of the freshwater wetlands in the CNMI (Stinson 1993).

The U.S. Geological Survey (USGS) recognizes eleven different watersheds on Saipan based on a 14-digit Hydrologic Unit Code (HUC) scale (CNMI-UWAWG 1998). Historical information on freshwater habitats and associated aquatic fauna of Saipan is relatively limited (Best 1981; Best and Davidson 1981). A recent comprehensive survey documented the status of these habitats and the distribution and relevant biology of both introduced and native species (McKagan et al. 2009).

#### Rota

About five streams originate from limestone caves on the southern area of Rota, yet there is confusion about the names of some of these streams (Best and Davidson 1981). The maximum elevation of Rota is 491 m (1,612 ft) on Mount Manira. The karst geology and groundwater resources of Rota have been investigated (Stafford et al. 2002; Carruth 2005), but there appear to be few studies of surface water resources.

#### Tinian

Lake Hagoi is a natural open-water and wetland area with a surface area of about 17 hectares (36.3 acres) located near the northern end of the island. Other than Lake Hagoi, there are no perennial or intermittent streams or lakes on Tinian (Best and Davidson 1981).

## Federated States of Micronesia

### Background

Climate throughout the region is warm tropical and rainfall is generally abundant. Thus, climatic conditions combined with topography contributes to complex and diverse freshwater ecosystems. A series of hydrologic studies conducted by the USGS in cooperation with FSM institutions provide detailed baseline information about freshwater resources of the region (van der Brug 1983a, b, 1984a, b; Anthony 1991, 1992, 1993; Anthony and Spengler 1993; Hamlin and Takasaki 1996). A bibliography of FSM water resource studies was compiled by Winter (1993).

Surficial freshwater resources on these islands are primarily associated with those having high topographic relief, principally the main islands of each of the legislative states: Chuuk, Kosrae, Pohnpei, and Yap. The main freshwater resources of the FSM are rivers and streams. Wetlands of the FSM were reviewed by Dahl (1993) and include mangrove forests (85% of a total of about 100 $km^2$ [38.7 $m^2$] for all islands combined), swamp forests (7%), freshwater marshes (6%), ivory nut palm forests (1.4%), and saline marshes (<1%).

## Freshwater Habitats of FSM: Chuuk State

Within the five island groups of Chuuk State, the Chuuk Island group is the largest, and is a complex of volcanic, mountainous islands surrounded by smaller, low-lying islands; these mountainous islands contain the greatest extent of surficial freshwater habitats, mostly streams, with relatively small drainage areas. The highest elevation is the summit of Mount Winipot, at 445 m (1,460 ft) above mean sea level on the island of Tol. The other four major island groups are clusters of coral atolls that lack surface water runoff but have groundwater lenses that fluctuate with rainfall and freshwater infiltration (Hamlin and Takasaki 1996). Water supply on the inhabited outer islands is obtained through rainwater catchment systems and shallow wells that provide fresh to brackish water.

## Freshwater Habitats of FSM: Kosrae State

The island has streams that drain radially from the interior, many with large drainage size relative to the area of the island. Data pertaining to drainage areas, elevation and geocoordinates of gaging stations, and discharge of rivers on Kosrae were summarized by van der Brug (1984a).

## Freshwater Habitats of FSM: Pohnpei State

The topography of Pohnpei Island and heavy rainfall results in steep-gradient streams that flow to the coasts, and many of the streams have spectacular cascading waterfalls. Extensive data for air and stream temperatures, rainfall, and river discharge were summarized by van der Brug (1984b).

## Freshwater Habitats of FSM: Yap State

Streams on Tomil-Gagil are perennial, but streams on Yap Island are dry about three months of the year. The dry season extends from December through April, and July through October is the wettest period. Hydrologic and other physical information for the island group was summarized by van der Brug (1983b). Nutrient characteristics of various inland water bodies of Yap Island were examined by Sanger and Hopper (1989).

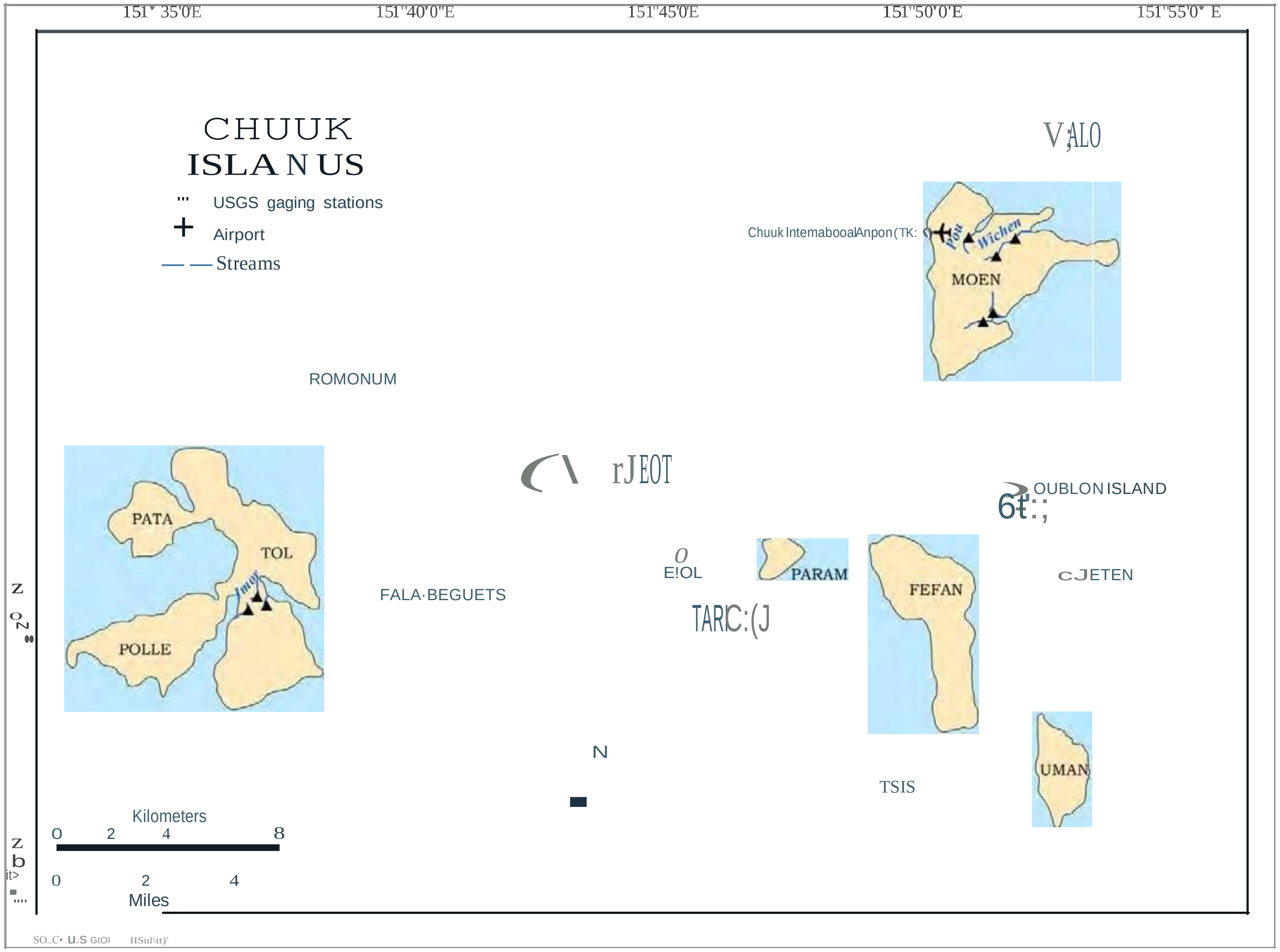


Figure 6. Chuuk Islands and location of U.S. Geological Survey gaging stations where streamflow data were obtained as summarized by van der Brug (1983a).

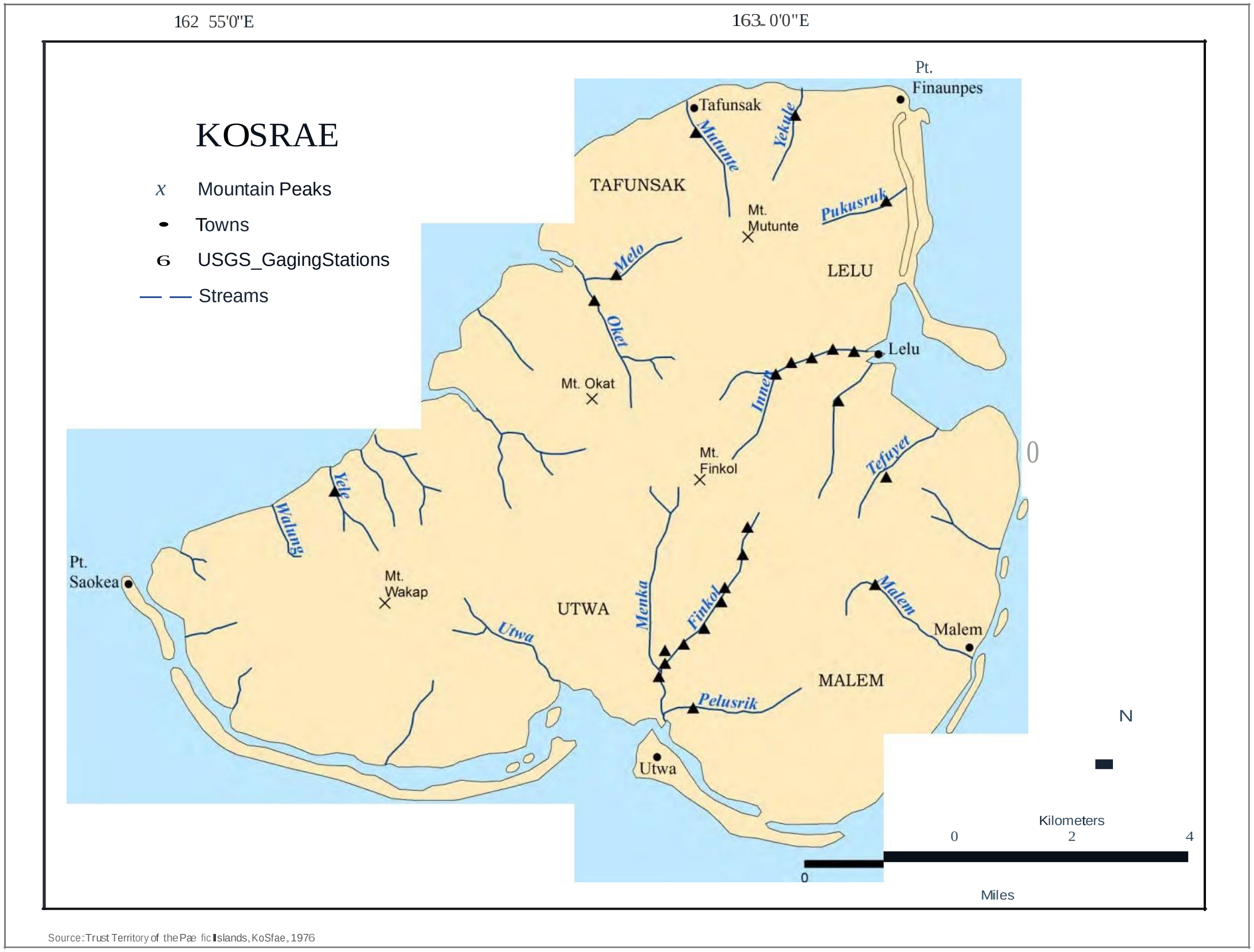


Figure 7. Streams of Kosrae and location of U.S. Geological Survey gaging stations where streamflow data were obtained as summarized by van der Brug (1984a).

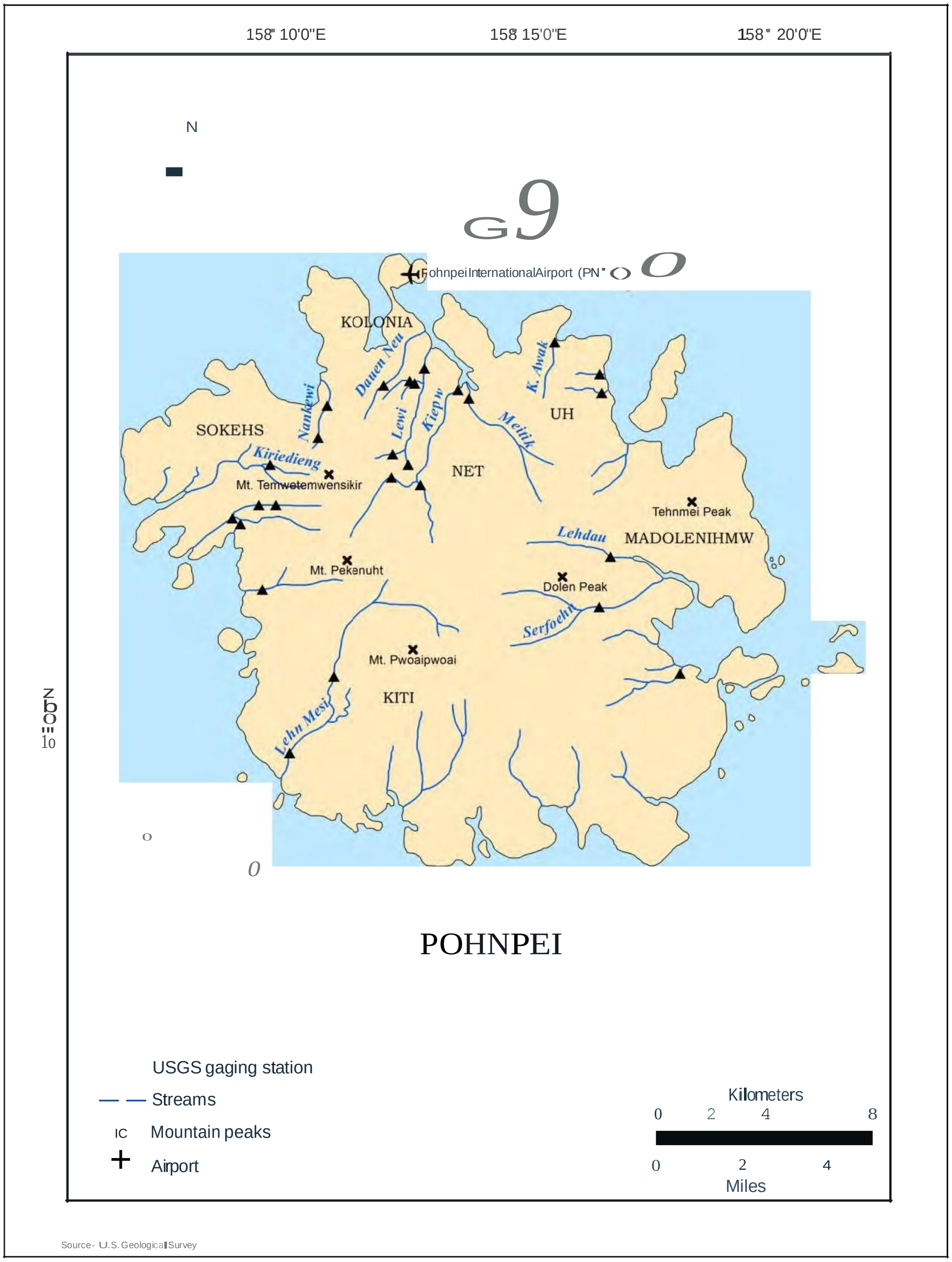


Figure 8. Major streams of Pohnpei and location of U.S. Geological Survey gaging stations where streamflow data were obtained as summarized by van der Brug (1984b).

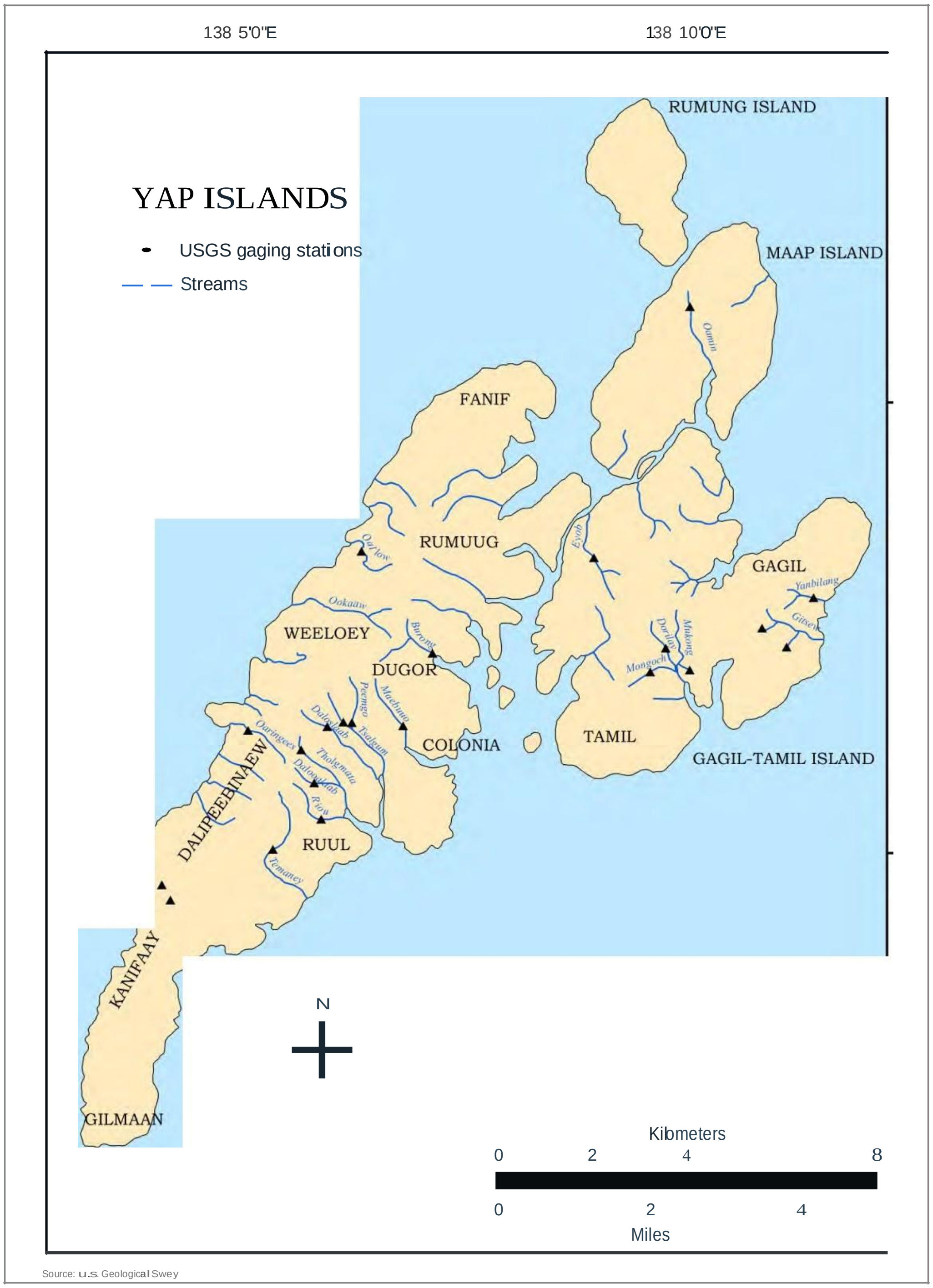


Figure 9. Yap Islands and location of U.S. Geological Survey gaging stations where streamflow data were obtained as summarized by van der Brug (1983b).

## Palau

### Freshwater Habitats of Palau

In Palau, streams are present only on the volcanic islands and are most highly developed on Babeldaob; streams on the other islands are small and usually dry part of the year. The largest lotic system is Ngerdorch River on Babeldaob, with a drainage area of about 47 $km^2$ (18 $mi^2$). Lake Ngardok on the North Fork of the Ngerdorch River is the largest natural lake in Micronesia, with a length of about 732 m (2,400 ft), maximum width of about 183 m (600 ft), depth of about 2.7 m (8.9 ft), and a total surface area of about 493 hectares (1,218 acres).

Lake Ngardok and the surrounding streams, marshes, and swamp forests have been collectively designated as a Ramsar Convention on Wetlands international site (RCS 2006) and are part of a conservation reserve to protect indigenous species, including a small breeding population of the Convention on International Trade in Endangered Species (CITES)-listed estuarine crocodile, *Crocodylus porosus*, numerous birds, fruit bats, freshwater fishes, aquatic plants, and other fauna and flora. The natural wetlands of Palau are diverse and include freshwater marshes, savannah wetlands, lowland swamps with low or high canopy, riparian wetlands, coastal saline marshes, mangrove forests, and cultivated wetlands used to grow taro (Scott 1993). There are also a number of artificial water bodies, including flooded bomb craters and phosphate quarries, roadside ditches, ponds, and reservoirs. The majority of the population in Koror is supplied by water from the Koror/Airai Public Water System (PWS) in southern Babeldaob; the main source of water is from the 75,000 $m^3$ (20-million-gallon) capacity Ngerimel Dam and Reservoir (Kingston 2004).

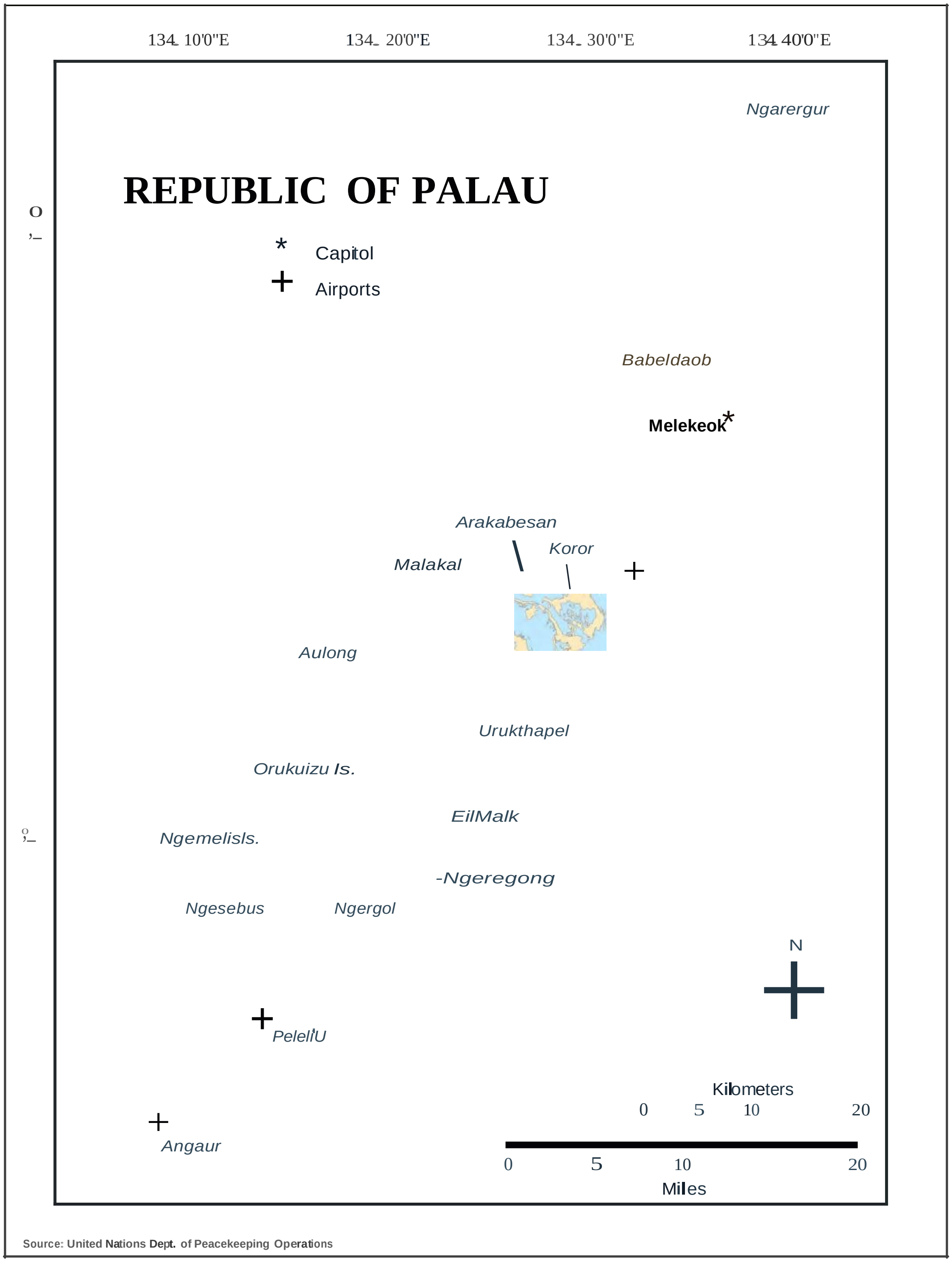


**Figure 10. Republic of Palau, western Caroline Islands.**

## Native Freshwater Fauna

Natural freshwater habitats of Micronesian islands have relatively depauperate aquatic faunas in comparison to continental faunas, yet endemism is generally high. The most prominent freshwater animals are fishes and macroinvertebrates. The family Gobiidae is the most common and diverse group of native fishes present in freshwater streams of the Micronesian islands. This group is also the most species-rich fish family in the world, and one that has colonized many inland waters on islands throughout the tropical Pacific (Ryan 1991). The most diverse and abundant invertebrates in streams and rivers of Micronesian islands are primarily atyid and palaemonid shrimps, neritid and thiarid gastropods, and larval insects.

Most of the fishes, mollusks, and crustaceans inhabiting Micronesian inland waters are migratory, euryhaline, or primarily marine. Euryhaline species normally inhabit estuaries or the open sea, but commonly enter fresh water. In contrast, primarily marine species are those that only occasionally or very rarely enter fresh waters. Those species that complete part of their life cycle in freshwater are diadromous; they use both freshwater and marine or brackish habitats during their life cycle. Most of the diadromous fish, decapod crustaceans and gastropod mollusks in Micronesia exhibit a distinctive form of diadromy referred to as amphidromy. Amphidromous species have the following characteristics: adult reproduction in fresh water; downstream passage or drifting of eggs or newly hatched larvae to the sea; a period of feeding and growing at sea; and juveniles or adults that return to fresh water to spend additional time feeding, growing, maturing, and reproducing (e.g., McDowall 1988; Kinzie 1990; Keith 2003; McDowall 2004; Evenhuis and Fitzsimons 2005; Fitzsimons et al. 2007; Iguchi 2007; McDowall 2007).

In contrast to amphidromy, some diadromous species are catadromous, spawning at sea and migrating up streams and rivers as juveniles or adults where they feed and mature. Many of the amphidromous and catadromous species that inhabit the Pacific islands have exceptional abilities to ascend rivers, often reaching high elevations above waterfalls (Fitzsimons et al. 2007). However, lack of anatomical and behavioral specializations in some species precludes them from ascending above the first impassable waterfall of a system, thereby limiting their freshwater occurrence to downstream segments of streams or rivers.

The presence of a marine larval stage of development has profound implications for the genetic connectivity of Micronesian stream fauna within and between islands. Donaldson and Myers (2002) analyzed the native fish faunas of different Micronesian islands, comparing differences in taxonomic richness and faunal similarities relative to island size and topographic relief. Patterns of species richness and similarity were compared using cluster analyses with pooled groups of (1) amphidromous, catadromous, euryhaline, and marine (ACEM) species; and (2) amphidromous and catadromous (ACFW) species. The taxonomic richness of both ACEM and ACFW assemblages was found to be greatest on large islands with high elevations compared to smaller islands with high elevations and islands of all sizes with low elevations only (Table 3). A comparison of similarity indices for ACEM species revealed two faunal components consisting of high and low islands, with two additional components partitioned between a Mariana Islands cluster and a Caroline Islands cluster (Fig. 11). However, the analysis of islands based on ACFW species was more complex, consisting of a cluster of low islands and small high islands in the Carolines island chain, with limited freshwater habitat, and

a second cluster partitioned into high islands and low islands that reflected the influence of both size and geography. In terms of their ecology, behavior, and distribution within the river-sea continuum, the anadromous and catadromous fishes throughout Oceania (encompassing Hawaii and Micronesia) are quite similar and share taxonomic affinities (Fitzsimons et al. 2002).

Table 3. Species richness of fishes from insular localities in Micronesia (Donaldson and Myers 2002).

| | Palau | Yap | Ifaluk/Woleai | Chuuk | Pohnpei | Kapingamarangi | Kosrae | Marshalls | Marianas | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Amphidromous and catadromous | 55 | 8 | 2 | 4 | 21 | 1 | 19 | 19 | 0 | 77 |
| Euryhaline | 50 | 10 | 8 | 5 | 23 | 7 | 6 | 24 | 9 | 65 |
| Marine | 8 | 4 | 0 | 2 | 7 | 1 | 4 | 18 | 0 | 24 |
| Total species | 113 | 22 | 10 | 11 | 52 | 9 | 29 | 61 | 9 | 166 |

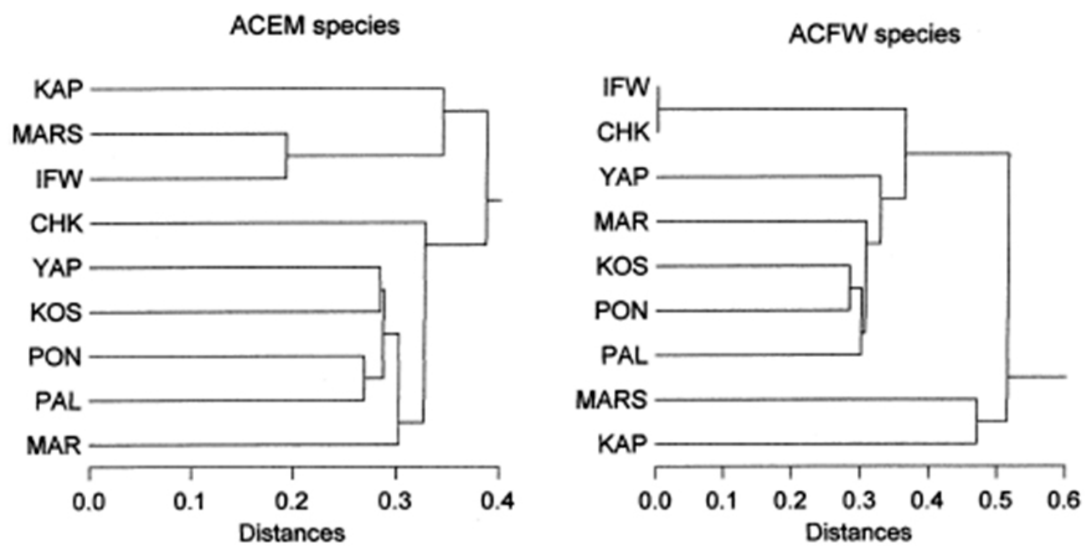


Figure 11. Cluster dendrograms among island groups indicating faunal similarities of native fishes occurring in Micronesian fresh waters, based on Sorenson Qualitative Similarity Index, a method robust for qualitative presence/absence data (Donaldson and Myers 2002). ACEM: amphidromous, catadromous, euryhaline, marine; ACFW: amphidromous and catadromous only.

## Mariana Islands

Myers and Donaldson (2003) provided a comprehensive, annotated checklist of fishes of the Mariana Islands and adjacent territorial waters. They reported a total of 1,106 species, of which 1,020 were inshore or epipelagic, represented mainly by coral reef inhabitants. Only nine species were reported as occurring exclusively in fresh water as adults, representing four families (Anguillidae, Eleotridae, Gobiidae, and Kuhlidae), but when all sources are considered, 12 species of these groups are listed for freshwater habitats of the Mariana Islands (Table 4). Many additional species that primarily occur in marine or estuarine habitats occasionally or regularly penetrate streams within or beyond the tidal zone, in some cases, naturally dispersing as far upstream as the first major downstream waterfall. There is uncertainty as to how many different species require freshwater habitats as part of their life history, because it is unclear as to which and how many species of *Eleotris* may occur in these habitats in the Mariana Islands (Table 4, footnote). Of the freshwater species, two gobies (*Stiphodon* sp. and *Sicyopus* sp.) are distributed only in the southern Mariana Islands and one (*Stenogobius* sp.) has been reported only from Guam; the other species are likely distributed throughout the remainder of the Mariana Islands. *Awaous ocellaris* is included in Guam's Comprehensive Wildlife Conservation Strategy (DAWR 2006). However, Watson (1992) noted misidentifications of *Awaous* species associated with the Pacific Plate; *A. ocellaris* is known from French Polynesia westward to the Solomon Islands, whereas *A. guamensis* ranges from Hawaii and the Mariana Islands southward to Vanuatu, New Caledonia, and Fiji.

The crustacean fauna of freshwater habitats in the Mariana Islands is dominated by small (< 4 mm), amphidromous shrimps of the family Atyidae (nine species, although a few may not be valid taxa). Other decapod crustaceans inhabiting inland waters of the Mariana Islands include members of the shrimp family Palaemonidae (two species) and members of the crab family Varunidae (three species) (Chace 1983; Leberer and Cai 2003; Paulay et al. 2003) (Table 5). At least six atyid shrimp species are found on the island of Guam (Leberer and Cai 2003). Most of the atyids present on Guam and other Mariana Islands are also found on islands throughout the Indo-Pacific region. The atyids are herbivores or detritivores and occur in a wide range of habitats, including inland fresh water, brackish and anchialine sites (Leberer and Cai 2003). Species of *Atyoida* and *Atyopsis* occur in shallow-water areas with high current, whereas *Caridina* species are found in slow-moving, deeper waters (DAWR 2006). There are at least two hypogean atyids found in caves and sinkholes on Guam (including anchialine caves). The two native palaemonid prawn species known from fresh waters of the Mariana Islands belong to the genus *Macrobrachium* (Table 5). These shrimp are omnivores and capable of surviving in intermittent headwaters, often representing the only aquatic fauna in such locations. Crabs in freshwater habitats of the Mariana Islands are an under-studied and inconspicuous component of the fauna (DAWR 2006), but there appear to be at least three species representing the family Varunidae (Paulay et al. 2003).

The gastropods of Guam were reviewed by Roth (1976) and Smith (2003). Inland waters of the island have at least 17 species of native prosobranch snails in two families, the Neritidae and Thiaridae (Table 6) (Smith 2003; DAWR 2006). The neritids are amphidromous, and adults in freshwater are herbivorous, feeding on algae and diatoms growing on hard substrates. The thiarids are typically found on sand or soft substrates, are omnivorous and feed on both plant and animal matter, and complete their entire life cycle in fresh water.

During the course of this study, aquatic insects were surveyed from a variety of habitats on Guam; a total of 35 aquatic insect species were collected. Three species of aquatic Heteroptera collected are island endemics: *Limnogonus lundbladi*, *Microvelia mariannarum*, and *Saldula guamensis*. A complete list of species, collecting sites, and other summary information for this insect survey is provided in **Appendix 3**.

The Mariana Islands have no native amphibians or aquatic or semi-aquatic reptiles.

Table 4. Native fishes of inland waters of the Mariana Islands (Kami et al. 1968; Myers and Donaldson 2003; DAWR 2006).

| Family | Species | Common name |
|---|---|---|
| Anguillidae | *Anguilla bicolor pacifica* Schmidt 1928 | Indian short-finned eel |
| | *Anguilla marmorata* Quoy & Gaimard 1824 | marbled freshwater eel |
| Eleotridae | *Eleotris fusca*[a] (Bloch & Schneider 1891) | dusky sleeper |
| | *Eleotris* sp.[b] | --- |
| | *Oxyeleotris* sp.[c] | --- |
| Gobiidae | *Awaous guamensis* (Valenciennes 1837) | Guam goby |
| | *Awaous ocellaris* (Broussonet 1782) | --- |
| | *Sicyopterus lagocephalus* (Pallas 1774) | red tailed goby |
| | *Sicyopus* sp. | red belly freshwater goby |
| | *Stenogobius* sp. | Marianas goby |
| | *Stiphodon percnopterygionus* Watson & Chen 1998 | dark finned goby |
| | *Stiphodon* sp. | emerald river goby |
| Kuhlidae | *Kuhlia rupestris* (Lacepède 1802) | rock flagtail |

[a] Taxonomic identification and number of species of *Eleotris* occurring in fresh waters of Guam and elsewhere in Micronesia is in question (B. Tibbatts, DAWR, written commun., 2011). Most early accounts cite presence of *E. fusca*. Myers and Donaldson (2003) listed *E. fusca* as presumed misidentification under *E. acanthopoma* Bleeker 1853 but did not treat this species as occurring exclusively in fresh waters as adults.

[b] Hypogean species reported from a single cave on Guam.

[c] Collected from Guam during present study; provisional identification.

Table 5. Native decapod crustaceans of inland waters of the Mariana Islands (Leberer and Cai 2003; Paulay et al. 2003). [See footnotes for alternative nomenclature as provided by the Integrated Taxonomic Information System (ITIS; *http://www.itis.gov/*). Common names from ITIS database]

| Family | Species | Common name |
|---|---|---|
| Atyidae | *Antecaridina lauensis* Edmondson 1935[a] | Lauan anchialine shrimp |
| | *Atyoida pilipes* (Newport 1847)[b] | koros shrimp |
| | *Atyoida serrata* (Bate 1888)[c] | |
| | *Atyopsis spinipes* (Newport 1847)[d] | soldier brush shrimp |
| | *Caridina brachydactyla* (de Man 1908)[e] | |
| | *Caridina mertoni* Roux 1911[f] | |
| | *Caridina typus* H. Milne-Edwards 1837[g] | |
| | *Halocaridinides trigonophthalma* (Fujino & Shokita 1975)[h] | |
| | *Halocaridinides* sp.[i] | |
| Palaemonidae | *Macrobrachium lar* (Fabricius 1798) | monkey river prawn |
| | *Macrobrachium* sp.[j] | |
| Varunidae | *Orcovita mollitia* Ng, Guinot, Iliffe 1996 | |
| | *Ptychognathus* sp. | |
| | *Varuna litterata* (Fabricius 1798) | |

[a] A hypogean species in anchialine caves; widespread in Indo-Pacific region; name not included in ITIS.

[b] Recorded from Mariana Islands in general; as *Atya pilipes* Newport 1847 in ITIS.

[c] Dubious record possibly based on misidentification; name not included in ITIS.

[d] Dubious record possibly based on misidentification; as *Atya spinipes* Newport 1847 in ITIS.

[e] Previously recorded from Guam as *C. longirostris* H. Milne-Edwards 1837 and in need of further study; considered by some authors as a variety of *C. nilotica*; name not included in ITIS.

[f] Previously recorded from Guam as *C. nilotica* (Roux 1833), *C. weberi* de Man 1892, and *C. serratirostris* de Man 1892; name not included in ITIS.

[g] Recorded from Mariana Islands in general without specific island identified.

[h] A hypogean species; Leberer and Cai (2003) speculated that individuals of this taxon reported by Maciolek (1983) likely represented the undescribed congeneric species; name not included in ITIS.

[i] A hypogean species under study (Leberer and Cai 2003).

[j] DAWR (2006) listed *M. latimanus* (Von Martens 1868) for Guam, a widespread Indo-Pacific species; however, Nelson et al. (1996) reported that this species has not been recorded from either Guam or Palau.

Table 6. Native aquatic gastropods of inland waters of Guam (Smith 2003; DAWR 2006).

| Family | Species |
|---|---|
| Neritidae | *Clithon corona* (Linnaeus 1758) |
| | *Clithon oualaniensis* (Lesson 1831) |
| | *Clithon sowerbianus* (Récluz 1843) |
| | *Neritina auriculata* Lamarck 1822 |
| | *Neritina pullicida* |
| | *Neritina pulligera* Linnaeus 1767 |
| | *Neritina squamipicta* Récluz 1843 |
| | *Neritina turrita* (Gmelin 1791) |
| | *Neritina variegata* (Lesson 1831) |
| | *Neritodryas subsulcata* (Sowerby 1836) |
| | *Septaria lineata* (Lamarck 1816) |
| Thiaridae | *Melanoides riqueti* (Grateloup 1840) |
| | *Melanoides tuburculata* (Müller 1774) |
| | *Stenomelania plicaria* (Born 1780) |
| | *Thiara granifera* Lamarck 1816 |
| | *Thiara scabra* Müller 1774 |

## Federated States of Micronesia

The numbers of species of amphidromous and catadromous native fishes from islands groups of the FSM reported by Donaldson and Myers (2002) were as follows: Chuuk, 4 species; Yap, 8 species; Kosrae, 19 species; and Pohnpei, 21 species. However, these numbers are provisional, because information concerning taxonomy and life history is incomplete and some areas have been inadequately surveyed. As elsewhere in Oceania, gobiids and eleotrids are the most species-rich groups in inland waters. Eels of the genus *Anguilla* are the most conspicuous catadromous fish species.

The first comprehensive survey of stream macrofauna in the eastern Caroline Islands was conducted in the Nanpil Kiepw River of Pohnpei (Maciolek and Ford 1987). In that survey, 15 fish species representing five families were collected. Of seven species of Gobiidae reported by these investigators, five were previously undescribed scydiines of the genera *Sicyopterus* and *Stiphodon*, four of which were subsequently described (Parenti and Maciolek 1993). Additional surveys of Pohnpei improved documentation of the diversity, distribution, and ecology of gobies inhabiting streams of the island and revealed the presence of two others, including at least one as-yet undescribed species of *Lentipes* (Nelson et al. 1996; Buden et al. 2001b). At least three of the goby species on Pohnpei are considered endemic. The herbivorous *Stiphodon caeruleus* is the most abundant and widespread goby on the island. Nelson et al. (1996) found significant differences in density of gobies between rivers and habitats, but these investigators found no significant river-habitat interaction in their statistical analysis, indicating that fish were not randomly distributed among habitats but that their habitat use was similar between streams. Riverine fish faunas of other islands in the FSM have been less intensively studied than those of Pohnpei, but some endemism, particularly in the sycydiine gobies, is known. Fish species occurring in streams and rivers of the large FSM islands are listed in Table 7.

Maciolek and Ford (1987) collected at least 28 species of invertebrates in their survey of the Nanpil Kiepw River, Pohnpei (11 crustaceans, 11 gastropods, five insects, and one annelid) (Table 8). A subsequent survey of headwater streams on Pohnpei yielded five different native shrimp taxa: two species of *Macrobrachium* and three species of atyids (Buden et al. 2001a). All of the species reported by Buden et al. (2001a) and many of those reported by Maciolek and Ford (1987) are widely distributed across the Indo-Pacific region. Maciolek and Ford (1987) noted additional insects known elsewhere on Pohnpei, typically occurring in quiet water habitats or stream areas less subjected to extreme flow fluctuations; these included odonates, caddisflies, dytiscid and hydrophilid beetles, mesoveliid bugs, and dipterans.

In recent years there have been a number of field surveys conducted on FSM islands to describe and document the odonate fauna (dragonflies and damselflies), especially of the winged adults (Buden and Paulson 2003; Paulson and Buden 2003; Buden 2004; Buden and Paulson 2007). A trend exists that corresponds with general island biogeography theory. Species richness of odonates decreases across the Micronesian archipelago from west to east (i.e., diversity diminishes farther from source areas), and larger islands have the greatest diversity (Paulson and Buden 2003). However, an exception is Pohnpei, to the east, which has high species richness, and is unique among the Caroline Islands in having six sympatric species of a single genus, *Teinobasis*. Eight of the 15 odonate species on Pohnpei are endemic (Paulson and Buden 2003). The odonate fauna of the large Micronesian island groups is summarized in Table 9.

Aquatic surveys of Yap Island provided information about native freshwater fishes, gastropods, crustaceans and insects (Nelson 1989a). At least eight native fish species representing seven families occur in Yap's streams and marshes: *Anguilla marmorata pacifica*, *Eleotris fuscus*, *Ophieleotris aporos*, *Periophthalmus vulgaris*, *Kuhlia rupestris*, *Scatophagus argus*, *Toxotes jaculator*, and *Ambassis* sp. (Nelson and Hopper 1989). Fourteen species of freshwater and brackish water gastropods were found in lotic and lentic habitats such as streams, ponds, taro plantations, mangrove swamps, and drainage ditches (Smith 1989). As throughout Micronesia, species of the families Neritidae and Thiaridae were dominant in freshwater habitats of Yap Island. *Neritina variegata*, *Melanoides plicaria*, and *Melanoides tuberculata* were the most abundant and widespread aquatic gastropods, occurring on rock, mud, and leaf-litter substrates. Likewise, the crustacean fauna of Yap Island includes at least eight species of atyid, palaemonid, and grapsid decapods. The atyid *Cardina typus* was found to be the most abundant and widespread decapod in freshwater habitats, typically occurring within about 1 to 2 km of the sea (Bright 1989). A survey of aquatic insects in freshwater habitats of Yap Island resulted in collection of about 50 species, with the greatest abundance and taxonomic richness present in lentic habitats and the lowest in streams (Schreiner and Nafus 1989). There appears to be relatively few, if any, endemic freshwater species on Yap Island, although there is need for additional surveys and critical taxonomic studies.

Freshwater faunistic studies of other FSM island groups are limited. General benthic surveys of some streams on Kosrae have been completed, but results have yet to be reported (B. Tibbatts, DAWR, and R.A. MacKenzie, U.S. Forest Service, oral commun., 2010). The freshwater faunas of the large islands of Chuuk remain poorly documented; surveys of these islands present special challenges for researchers due to logistics and various social and cultural impediments (B. Lynch, College of Micronesia, oral commun., 2010).

Table 7. Stream fishes of large islands of the Federated States of Micronesia (Maciolek and Ford 1987; Parenti and Maciolek 1993; Nelson et al. 1996; Buden et al. 2001b; Donaldson and Myers 2002). [A few species are omitted if their habitat occurrence is primarily mangrove, estuarine, or tidal reach within fresh water. Common names from FishBase® (Froese and Pauly 2011).]

| Family | Species | Common name |
|---|---|---|
| Ambassidae | *Ambassis buruensis* Bleeker 1856 | Buru glass perchlet |
| Anguillidae | *Anguilla bicolor pacifica* Schmidt 1928 | Indian short-finned eel |
| | *Anguilla marmorata* Quoy & Gaimard 1824 | marbled freshwater eel |
| Eleotridae | *Bunaka gyrinoides* (Bleeker 1853) | greenback guavina |
| | *Butis amboinensis* (Bleeker 1853) | olive flathead gudgeon |
| | *Eleotris fusca* (Forster 1801) | dusky sleeper |
| | *Ophieleotris aporos* (Bleeker 1854) | snakehead gudgeon |
| | *Ophiocara porocephala* (Valenciennes 1837) | spangled sleeper |
| | *Oxyeleotris lineolatus* (Steindachner 1867) | sleepy cod |
| Gobiiidae | *Glossogobius celebius* (Valenciennes 1837) | Celebes goby |
| | *Glossogobius giurus* (Hamilton 1822) | tank goby |
| | *Lentipes* sp. (from Pohnpei) | --- |
| | *Mugilogobius cavifrons* (Weber 1909) | mangrove goby |
| | *Redigobius bikolanus* (Herre 1927) | speckled goby |
| | *Redigobius tambujon* (Bleeker 1854)[a] | --- |
| | *Sicyopterus eudentata* Parenti & Maciolek 1993 | --- |
| | *Sicyopterus lividus* Parenti & Maciolek 1993 | --- |
| | *Sicyopterus* sp. (from Kosrae) | --- |
| | *Sicyopus nigriradiatus* Parenti & Maciolek 1993 | --- |
| | *Stenogobius* sp. (from Chuuk) | --- |
| | *Stiphodon caeruleus* Parenti & Maciolek 1993 | --- |
| | *Stiphodon* sp. (from Kosrae) | --- |
| Kuhlidae | *Kuhlia marginata* (Cuvier 1829) | dark-margined flagtail |
| | *Kuhlia rupestris* (Lacepède 1802) | rock flagtail |
| Syngnathidae | *Hippichthys spicifer* (Rüppell 1838) | bellybarred pipefish |
| | *Microphis retzii* (Bleeker 1856) | ragged-tail pipefish |

[a] Donaldson and Myers (2002) listed *Redigobius roemeri* for Pohnpei, but this species is considered a synonym of *R. tambujon* (Eschmeyer 2011).

Table 8. Native aquatic macroinvertebrates of the Nanpil Kiepw River and other streams of Pohnpei reported by Maciolek and Ford (1987), updated to reflect current taxonomy and nomenclature.

| Phylum/Order | Family | Taxon | Source of taxonomic authority |
|---|---|---|---|
| Annelida-Polychaeta | Nereidae | *Ceratonereis* sp. Kinberg 1866 | ITIS (*http://www.itis.gov/*) |
| Crustacea-Amphipoda | Corophiidae | *Grandidierella* sp. Coutière 1904 | ITIS (*http://www.itis.gov/*) |
| Crustacea-Decapoda | Atyidae | *Atyopsis pinipes* (Newport 1847) | Leberer and Cai(2003) |
| | | *Atyoida pilipes* (Newport 1847) | Leberer and Cai (2003) |
| | | *Caridina brachydactyla* de Man 1908 | Leberer and Cai (Leberer and Cai 2003) |
| | | *Caridina longirostris* H. Milne-Edwards 1837 | Leberer and Cai (2003) |
| | | *Caridina typus* H. Milne-Edwards 1837 | Leberer and Cai (2003) |
| | | *Caridina vitiensis* Borradaile 1898 | Karge et al. (2010) |
| | | *Caridina weberi* de Man 1892 | Leberer and Cai (2003) |
| | Palaemonidae | *Macrobrachium lar* (J.C. Fabricius 1798) | ITIS (*http://www.itis.gov/*) |
| | | *Marcobrachium latimanus* (Von Martens 1868) | ITIS (*http://www.itis.gov/*) |
| | Grapsidae | *Parasesarma* sp. De Man 1895 | *http://www.marinespecies.org/index.php* |
| Insecta-Hemiptera | Gerridae | *Halobates mariannarum* Esaki 1924 | *http://www.marinespecies.org/index.php* |
| Insecta-Lepidoptera | Pyralidae | *Petrophila* (?) sp.[a] Guilding 1830 | ITIS (*http://www.itis.gov/*) |
| | Cosmopterigidae | Unidentified sp. | |
| Insecta-Diptera | Chironomidae | Unidentified spp. | |
| Insecta-Trichoptera | Hydrophilidae | *Oxyethira* sp. Eaton 1873 | ITIS (*http://www.itis.gov/*) |
| Mollusca-Gastropoda | Neritidae | *Clithon corona* (Linnaeus 1758) | *http://neritopsine.lifedesks.org/* |
| | | *Neritina petitii* (Récluz 1841) | *http://neritopsine.lifedesks.org/* |
| | | *Neritina pulligera* (Linnaeus 1767) | *http://neritopsine.lifedesks.org/* |
| | | *Neritodryas subsulcata* (Sowerby 1836) | *http://neritopsine.lifedesks.org/* |
| | | *Neritona macgillivrayi* (Reeve 1855) | *http://neritopsine.lifedesks.org/* |
| | | *Septaria lineata* (Lamarck 1816) | *http://www.sealifebase.org/* |
| | | *Septaria porcellana* (Linnaeus 1758) | *http://neritopsine.lifedesks.org/* |
| | | *Septaria sanguisuga* (Reeve 1856) | *http://neritopsine.lifedesks.org/* |
| | | *Vittina variegata* (Lesson 1831) | *http://neritopsine.lifedesks.org/* |
| | Thiaridae | *Melanoides tuberculatus* (Müller 1774) | ITIS (*http://www.itis.gov/*) |
| | | *Thiara scabra* Müller 1774 | *http://www.sealifebase.org/* |

[a] Given as *Parargyractis* (?) sp. In Maciolek and Ford (1987); genus cited as junior synonym in ITIS.

Table 9. Native species of Odonata in Micronesia and distribution by island group (Paulson and Buden 2003).

| Family | Species | Palau | Yap | Chuuk | Pohnpei | Kosrae |
|---|---|---|---|---|---|---|
| Platycnemididae | *Drepanosticta palauensis* Lieftinck 1962 | X | | | | |
| | *Agriocnemis femina femina* (Brauer 1868) | X | X | | | |
| | *Ischnura aurora* (Brauer 1865) | X | X | X | X | X |
| | *Ischnura heterosticta* (Burmeister 1839) | X | | | | |
| | *Pseudagrion palauense* Lieftinck 1962 | X | | | | |
| | *Teinobasis aerides* Lieftinck 1962 | | | | X | |
| | *Teinobasis ariel* Lieftinck 1962 | | | | X | |
| | *Teinobasis budeni* Paulson 2003 | | | | X | |
| | *Teinobasis carolinensis* Lieftinck 1962 | | | X | | |
| | *Teinobasis fortis* Lieftinck 1962 | | | | X | |
| | *Teinobasis nigrolutea* Lieftinck 1962 | | | | X | |
| | *Teinobasis palauensis* Lieftinck 1962 | X | | | | |
| | *Teinobasis ponapensis* Lieftinck 1962 | | | | X | |
| Aeshnidae | *Anaciaeschna jaspidea* (Burmeister 1839) | X | X | | | |
| | *Anax guttatus* (Burmeister 1839) | X | | | X | X |
| Cordulidae | *Hemicordulia erico* Asahina 1940 | | | | | X |
| | *Hemicordulia haluco* Asahina 1940 | | | | X | |
| | *Hemicordulia lulico* Asahina 1940 | X | X | | | |
| Libellulidae | *Agrionoptera cardinalis* Lieftinck 1962 | X | | | | |
| | *Agrionoptera insignis yapensis* Lieftinck 1962 | | X | | | |
| | *Agrionoptera sanguinolenta sanguinolenta* Lieftinck 1962 | | | | X | |
| | *Agrionoptera sanguinolenta pusilla* Lieftinck 1962 | | | X | | |
| | *Diplacodes bipunctata* (Brauer 1865) | X | X | X | X | X |
| | *Macrodiplax cora* (Brauer 1867) | X | X | | | |
| | *Neurothemis terminata* Ris 1911 | X | X | | | |
| | *Pacificothemis esakii* Asahina 1940 | | | | X | |
| | *Pantala flavescens* (Fabricius 1798) | X | X | | X | X |
| | *Rhyothemis phyllis vitellina* Brauer 1868 | X | X | | | |
| | *Tholymis tillarga* (Fabricius 1798) | X | X | X | X | X |
| | *Tramea loewii* Brauer 1866 | | X | | | |
| | *Tramea transmarina euryale* Selys 1876 | X | X | | | |
| | *Tramea transmarina propinqua* Lieftinck 1962 | | | X | X | X |
| | *Zyxomma petiolatum Rambur* 1842 | X | | | | |
| | **Total species** | **18** | **13** | **6** | **15** | **7** |

## Palau

Fehlmann (1960) conducted a detailed study that provided information on the identification and distribution of fishes and invertebrates inhabiting Arakitaoch Stream on the island of Babeldaob. Based on faunal gradient and stream characteristics, four different reaches or zones were recognized: mangrove, lower graded, cascade, and source. Subsequent to Fehlmann's study, a synoptic checklist of the inland fishes of Palau was published in which a total of 43 native species representing 18 families were enumerated, including four introduced species (Bright and June 1981) (Table 10). Several of the species listed by these authors are primarily marine or estuarine; their occasional occurrence in rivers is confined to downstream tidal reaches and mangrove areas. Species richness was greatest for gobies (12 species) and sleepers (9 species). As noted by Bright and June (1981), the most extensive habitat suitable for diadromous or freshwater species in Palau are the streams and rivers of Babeldaob. However, there are also intermittent streams on Koror and Arakabesang, and on all three islands there are additional freshwater habitats that support aquatic communities.

An intensive, quantitative survey of freshwater fishes was conducted in the upper reaches of Babeldaob's Ngermeskang River, one of Palau's largest inland drainages (Nelson et al. 1995). These investigators obtained density estimates for 13 species, based largely on visual surveys conducted by snorkelers (although a few specimens were collected with nets and a backpack electroshocker) to aid in verifying visual survey identifications. Maximum densities of selected gobiid fish ranged from 0.4 individuals per $m^2$ for *Redigobius bikolanus* to more than 11.0 individuals per $m^2$ for female *Stiphodon elegans*, with the highest mean density of 5.2 individuals per $m^2$ for the latter. There was a distinct difference in community composition between river segments below and above the large Ngermeskang Waterfall (Table 11). Fishes (e.g., *Kuhlia* spp.) incapable of ascending steep waterfalls were confined to the downstream reaches. Nelson et al. (1995) provided quantitative evidence to support the qualitative observations of Fehlmann (1960) that habitat type defined by relative water column velocity (riffle, run, and pool) as well as substrate (cobble, boulder, and bedrock) are determinants of the distribution and abundance of native fishes in these high-gradient rivers and streams.

Fehlmann (1960) documented the invertebrate fauna of Arakitaoch Stream, principally in the mangrove, lower graded, and cascade sections. Several species of crustaceans and mollusks, including all bivalves collected, were only present in mangrove areas. As in other regions of Micronesia, the freshwater fauna was dominated by atyid and palaemonid shrimps and thiarid and neritid snails. The atyid shrimps present were composed of only one or a few species of *Atya* or a related genus, and these were found to be most abundant in the cascade zone (Fehlmann 1960). Palaemonids were identified as one or two species of *Macrobrachium* (most likely including *M. lar*). Gastropods in the lower graded zone were limited to *Neritina pulligera*, in moderate abundance, and *Thiara amarula* in low abundance. The cascade zone had the greatest snail species richness, which in decreasing order of abundance was as follows: *Neritina pulligera*, *N. cornea*, *N. variegata*, *Stenomelania* sp. cf. *hastula*, and *T. amarula*. Only *N. cornea* was found in the source zone and was in lower abundance than in the cascade zone.

During the course of this study, aquatic insects were surveyed from a variety of habitats on Palau, mostly Babeldaob streams; we collected a total of 28 aquatic insect species. We conservatively estimated that at least four island endemics were present, including three damselflies (*Drepanosticta palauensis, Pseudagrion palauense*, and *Teinobasis palauensis*) and a gyrinid (whirligig) beetle, *Dineutus* (*Spinodineutes*) sp. cf. *heterandrus*. An *Ischnura* damselfly found in lentic habitats on Palau was not identified conclusively, but, because it is not a widespread species such as *Ischnura aurora* or *Agriocnemus femina femina*, it is likely that it at least is indigenous if not possibly endemic to Palau. A complete list of species, collecting sites, and other summary information for this insect survey is provided in Appendix 3.

Palau has Micronesia's only native amphibian, the Palau frog *Platymantis pelewensis*, found throughout all but the southwest islands and endemic to the Palau archipelago, from Kayangel Atoll in the north to Angaur in the south. Although not considered to be aquatic (there is no tadpole stage and breeding is in terrestrial habitats), the species is common to abundant and is found in a variety of habitats, thriving in human-inhabited areas and often reaching very high densities in caves and abandoned war bunkers (Crombie and Pregill 1999). The Palau frog has direct development (Atoda 1950), but detailed information about reproduction and other aspects of its natural history is limited (Crombie and Pregill 1999).

The saltwater or estuarine crocodile (*Crocodylus porosus*) is native to Palau, although its numbers have declined in recent history. In the 1960s, there were systematic efforts to eradicate saltwater crocodiles from Palau as a result of attacks on humans. There have been persistent rumors that other crocodile species are present on Palau, presumably based partly on the possibility that some non-native crocodiles imported to the island in the 1930s may have escaped (Crombie and Pregill 1999). There are a few confirmed and some unconfirmed reports of saltwater crocodiles in the Caroline Islands outside of Palau. Their presence on these other islands is likely the result of natural dispersal (island hopping) across expanses of sea as waifs. Such events are considered rare; for example, there is a single record of a 380 cm (12.5 ft) male crocodile captured on the island of Pohnpei, about 1,360 km (845 mi) to the north of the Bismark Archipelago and 2,400 km (1,490 mi) to the east of Palau where this species is native (Allen 1974; Eldredge 1994; Crombie and Pregill 1999; Buden 2000).

Table 10. Native and nonindigenous fish species reported by Bright and June (1981) from inland waters of Palau, updated to reflect changes in taxonomy and nomenclature. [Nonindigenous species shaded in gray]

| Family | Species | Common name |
|---|---|---|
| Albulidae | unidentified larvae | --- |
| Ambassidae | *Ambassis interruptus* Bleeker 1852 | long-spined glass perchlet |
| Anguillidae | *Anguilla bicolor pacifica* Schmidt 1928 | Indian short-finned eel |
| | *Anguilla marmorata* Quoy & Gaimard 1824 | giant mottled eel |
| Antennariidae | *Antennarius nummifer* (Cuvier 1817) | spotfin frogfish |
| Cobitidae | *Misgurnus anguillicaudatus* (Cantor 1842) | Oriental weatherfish |
| Cyprinidae | *Puntius sealei* (Herre 1933) | --- |
| Eleotridae | *Bunaka gyrinoides* (Bleeker 1853) | greenback guavina |
| | *Butis amboinensis* (Bleeker 1853) | olive flathead gudgeon |
| | *Eleotris fusca* (Forster 1801) | dusky sleeper |
| | *Eleotris melanosoma* Bleeker 1852 | broadhead sleeper |
| | *Giuris margaritacea* (Valenciennes 1837) | snakehead gudgeon |
| | *Hypseleotris cyprinoides* (Valenciennes 1837) | tropical carp gudgeon |
| | *Hypseleotris guentheri* (Bleeker 1875) | rainbow gudgeon |
| | *Ophiocara porocephala* (Valenciennes 1873) | spangled sleeper |

Table 10. Native and nonindigenous fish species reported by Bright and June (1981) from inland waters of Palau, updated to reflect changes in taxonomy and nomenclature. [Nonindigenous species shaded in gray]

| Family | Species | Common name |
|---|---|---|
| | *Oxyeleotris* sp.[a] | --- |
| | *Xenisthmus* sp. | --- |
| Gobiidae | *Awaous grammepomus* (Bleeker) | scribbled goby |
| | *Glossogobius celebius* (Valenciennes 1837) | Celebes goby |
| | *Mugiligobius* sp. | --- |
| | *Pandaka* sp. | --- |
| | *Pseudogobius javanicus* (Bleeker 1856) | --- |
| | *Redigobius balteatus* (Herre 1935)[b] | rhinohorn goby |
| | *Redigobius bikolanus* (Herre 1927) | speckled goby |
| | *Redigobius oyensi* (de Beaufort 1913)[c] | --- |
| | *Redigobius tambujon* (Bleeker 1854) [c] | --- |
| | *Sicyopterus micrurus* (Bleeker 1853) | clinging goby |
| | *Sicyopus zosterophorus* (Bleeker 1857) | ornate goby |
| | *Smilocicyopus fehlmanni* (Parenti & Maciolek 1993) | --- |
| | *Stenogobius fehlmanni* (Valenciennes 1837) | chinstripe goby |
| | *Stiphodon elegans* (Steindachner 1879) | --- |
| Kraemeriidae | *Kraemeria cunicularia* Rofen 1858 | transparent sand dart |
| Kuhliidae | *Kuhlia marginata* (Cuvier 1829) | dark-margined flagtail |
| | *Kuhlia rupestris* (Lacepède 1802) | rock flagtail |
| Megalopidae | *Megalops cyprinoides* (Broussonet 1782) | Indo-Pacific tarpon |
| Moringuidae | *Moringua* sp. | --- |
| Mugilidae | *Liza melinoptera* (Valenciennes 1836) | otomebora mullet |
| Muraenidae | *Gymnothorax polyuranodon* (Bleeker 1853) | freshwater moray |
| Poeciliidae | *Poecilia reticulata* (Peters 1859) | guppy |
| | *Xiphophorus maculatus* (Günther 1866) | southern platyfish |
| Scatophagidae | *Scatophagus argus* (Linnaeus 1766) | spotted scat |
| Synbranchidae | *Ophisternon bengalense* McClelland 1844 | Bengal eel |
| Syngnathidae | *Hippichthys spicifer* (Rüppell 1838) | bellybarred pipefish |
| | *Microphis brachyurus* (Bleeker 1853) | short-tailed pipefish |
| | *Microphis brevidorsalis* (de Beaufort 1913) | stream pipefish |
| | *Microphis leiaspis* (Bleeker 1853) | barhead pipefish |

[a] Provisional identification based on specimens collected from the present study; not reported by Bright and June (1981) or Fehlmann (1960).
[b] Listed by Larson (2010) from Palau; not reported by Bright and June (1981).
[c] Bright and June (1981) included both *R. tambujon* and *R. sapangus*, but these two species are considered to be synonyms (Eschmeyer 2011).

Table 11. Distribution of native freshwater fishes in the Ngermeskang River, Palau, along a habitat gradient spanning a major waterfall. [Data based on results of field surveys conducted by Nelson et al. (1995). Methods involved visual census conducted by shoreline observers and by underwater observers using mask and snorkel. Occurrence by reach based on whether species was detected during survey: +, present; –, absent.]

| Family | Species | Below Fall | Above Fall | Headwaters |
|---|---|---|---|---|
| Anguillidae | *Anguilla marmorata* | + | + | – |
| Eleotridae | *Bunaka gyrinoides* | – | + | – |
| Eleotridae | *Giuris margaritacea* | – | + | + |
| Gobiidae | *Glossogobius celebius* | + | + | + |
| | *Redigobius bikolanus* | + | – | – |
| | *Sicyopus* sp.1 (red male) | + | + | + |
| | *Sicyopus* sp. 2 (striped male) | – | + | – |
| | *Sicyopus* spp. (females) | + | + | + |
| | *Sicyopus zosterophorum* | – | + | – |
| | *Stiphodon caeruleus*[a] | – | + | + |
| | *Stiphodon elegans* | + | + | + |
| Kuhliidae | *Kuhlia marginata* | + | – | – |
| | *Kuhlia rupestris* | + | – | – |
| Toxotidae | *Toxotes jaculatrix* | + | – | – |

[a] Species described from Pohnpei (Parenti and Maciolek 1993); identification requires confirmation by qualified taxonomist.

## Introduced Freshwater Fauna

### Mollusks

A variety of nonindigenous aquatic mollusks, mostly gastropods (snails), have been introduced to inland waters of Pacific islands. Recent reviews of mollusk introductions to the region summarized information on both terrestrial and aquatic nonindigenous snails and on the single nonindigenous freshwater bivalve introduced to the region, the Asian freshwater clam (*Corbicula fluminea*) (Cowie 2000b, a). Considerable evidence indicates that many of the native Pacific insular gastropod faunas are being homogenized by the introduction and spread of invasive snails (Cowie 1998a, 2000b). Among nonindigenous species, some have been introduced intentionally and others accidentally. By virtue of their diversity, endemism, and limited dispersal capabilities, the native terrestrial gastropod faunas of tropical Pacific islands are disappearing, and are particularly threatened by nonindigenous mollusks. In contrast to native terrestrial snails, the native freshwater snail fauna of tropical Pacific islands consist of relatively few species and many have wider geographic distributions. Consequently, the native freshwater snail fauna is generally less imperiled overall than that of the terrestrial fauna; however, they also are threatened by introduced species and other factors.

The most notable introductions of freshwater gastropods in the Pacific are apple snails (Ampullariidae) of the genera *Pomacea* and *Pila*. Among terrestrial and aquatic mollusks, “channeled” or “golden” apple snail, *Pomacea canaliculata* is considered an especially harmful pest (Cowie et al. 2009). The taxonomy of ampullarids is inadequately resolved; some species are difficult to distinguish based on morphology, and species identifications of some introduced populations, when investigated closely, may reveal greater diversity and more complex history of introductions than initially recognized (Rawlings et al. 2007). Apple snails (especially *P. canaliculata*) have been widely introduced around the world as food and for aquaculture (Eldredge 1994; Cowie 1998b; Lach and Cowie 1999; Cowie 2000b; Cowie et al. 2007). They are also popular among aquarists (Perera and Walls 1996). Both aquatic and terrestrial species may also be associated with transport via the horticulture industry. When introduced to tropical areas outside of their native ranges, apple snails may become serious agricultural pests on cultivated crops such as taro and rice (Naylor 1996; Cowie 2002; Qiu and Kwong 2009). Apple snails in Micronesia are present on Guam and in the CNMI; on Guam they were first observed in the 1980s (Smith 2003). The ampullarid snail *Pila conica* was introduced to Palau in the mid-1980s, but was thought to have been eradicated by 1987 (Eldredge 1994). Both *Pomacea canaliculata* and *Pila conica* are intermediate hosts for several parasites of humans and their potential as vectors of human disease should not be overlooked.

Additional freshwater snail species have been introduced to Guam, including *Fossaria viridis* (Quoy and Gaimard) and at least one viviparid and two planorbid species (Eldredge 1994; Cowie 2000b). Most of these introductions are thought to have been accidental or intentional releases associated with the aquarium trade.

Invasive snails and other mollusks receive relatively little attention, but they can have important impacts on agriculture, biodiversity, and human health, and can become major public nuisances (Cowie et al. 2009). Negative impacts to native species on Pacific islands appear varied but are generally not well studied. Some predatory terrestrial snails have been intentionally introduced in misguided efforts to use them as biocontrol agents, resulting in severe depredation of native species (Cowie 1998b). Introduced snails in all habitats are also implicated in the decline of native snails through competition. Additionally, concerns often arise over introductions of gastropods due to the fact that many species may serve as intermediate hosts for parasites that are transmissible to humans or livestock (Madsen and Frandsen 1989; Eldredge 1994).

No records were found to indicate that bivalve mollusks have been introduced to Micronesia. However, the freshwater Asiatic clam *Corbicula fluminea* is known from Hawaii (Cowie 2000b), and it has an extensive nonindigenous distribution in North America. Introductions of *C. fluminea* may have substantial ecological as well as economic impacts.

## Crustaceans

A small number of freshwater decapod crustacean species have been introduced to inland waters of Pacific islands. At least five are considered established on at least one Pacific island: the giant river prawn (or giant freshwater prawn) *Macrobrachium rosenbergii* and giant Malaysian prawn *Macrobrachium lar* (both of the family Palaemonidae); the shrimp *Neocaridina denticulate sinensis* (Atyidae); the red swamp crawfish *Procambarus clarkii* (Cambaridae); and the Australian redclaw crayfish *Cherax quadricarinatus* (Parastacidae). To date, the only established wild populations are known from Hawaii (4 species) and New Caledonia (1 species). A few introductions have occurred on islands in Micronesia, including Guam and Palau, but without evidence of establishment in the wild (Eldredge 2000). The introduction of freshwater crustaceans to Pacific islands has typically been associated with aquaculture and the aquarium trade (Eldredge 2000).

The species of greatest interest in aquaculture has been the giant river prawn *Macrobrachium rosenbergii*, due to its large size and advanced culture technology. There has been long-standing confusion with its nomenclature that has been partly resolved by examination of morphological characters and use of modern genetic analyses (Wowor and Ng 2007; Iketani et al. 2011). Wowor and Ng (2007) recognized two distinct species for what has historically been regarded as the single species *M. rosenbergii* (and two subspecies according to some researchers), and distinguished them using discernible morphological characters. *Macrobrachium rosenbergii* (in the strict sense) occurs in Australia, Papua New Guinea, eastern Indonesia, and the Philippines. *Macrobrachium dacqueti*, an important food species extensively cultured in captivity and harvested from the wild, occurs throughout southern and southeastern Asia.

Eldredge (1994, 2000) provided a history of intentional introductions of *Macrobrachium* associated with aquaculture for Hawaii, Guam, Palau, and other regions of the Pacific. Movements of species have been in different directions. For instance, shipments of *M. rosenbergii* for aquaculture that originated in Hawaii (with original stock from Malaysia, and possibly elsewhere) were shipped to Guam, Palau, and a few South Pacific islands. Conversely, *M. lar*, which is native to Micronesia, was shipped from Guam to Hawaii, where it became established and now potentially competes with Hawaii's only native freshwater prawn, *M. grandimanus*.

Hawaii has other species of introduced crustaceans that are potentially of concern as possible risk to Micronesian islands. Atyid shrimps native to Southeast Asia are present on Oahu and likely escaped or were released by means of the aquarium trade (Englund and Cai 1999; Eldredge 2000). The freshwater crayfish *Procambarus clarkii* is also established in Hawaii, where it has had agricultural impacts (Eldredge 2000). Invasive crayfishes have had deleterious ecological and economic impacts in places where they have been introduced outside of their native ranges (Gherardi 2007). Thus, from a biosecurity perspective for Micronesia, crayfishes should be considered high risk and subject to scrutinous monitoring.

## Amphibians

Micronesia has only one native amphibian species, the Palau frog, *Platymantis pelewensis*, which is endemic to various islands of Palau where it is associated with freshwater environments, and reportedly, certain slightly brackish-water habitats (Crombie and Pregill 1999). However, a number of nonindigenous amphibians, mostly anurans (frogs and toads), have been introduced to Micronesia and several have become established, mostly on Guam (Table 12). The pathways by which nonindigenous amphibians have been introduced throughout many areas of the Pacific, as elsewhere in the world, are varied (Eldredge 1994; Pitt et al. 2005; Christy et al. 2007b; Kraus 2009b; USDA-APHIS 2010).

The first nonindigenous anuran to be introduced to the Pacific, and now one of the most widespread terrestrial vertebrates in the world, is the cane or marine toad, *Rhinella marina* (Easteal 1981; Eldredge 1994, 2000; Lever 2003; Kraus 2009a). In the Pacific, cane toads were first introduced to Hawaii, and were subsequently distributed extensively, and mostly intentionally, for biocontrol of various insect pests and garden slugs (e.g., *Veronicella leydigi*). Detailed historical accounts of introductions in Oceania have been summarized by various authors (e.g., Eldredge 1994; Crombie and Pregill 1999; Eldredge 2000; Lever 2003). The cane toad is now established virtually everywhere on the main island groups of Micronesia, and in some places it is extremely abundant. An extensive body of literature exists concerning the cane toad's global redistribution and its effects on native species and humans. The cane toad is not established on all islands within Micronesia and preventing its further spread may be valuable to consider.

There is general consensus that in many places where it has been introduced *R. marina* has had significant economic, ecological, and human-health impacts (Easteal 1981; Lever 2003). Ecological impacts include the following: (1) predation by cane toads on native invertebrates and vertebrates; (2) toxicity to native species that eat or come into contact with cane toads; (3) direct competition between cane toads and native species for food, spawning sites, and other resources; and (4) reduced native populations of species that provide natural controls of other pest species (Lever 2003). The list of impacts on human welfare is extensive, including, but not limited to the following: (1) pollution of potable water supplies, swimming pools, and other water resources; (2) blocking of drains by dead, decomposing toads; (3) death of domestic pets, and, although rare, humans; (4) erosion of earthen dams and berms by burrowing toads; (5) spread of human parasites, diseases, and other pathogens transmissible to humans (e.g., dysentery, *Salmonella*); (6) traffic hazards from dead toads on roadways; and (7) high costs of environmental monitoring, control, and mitigation programs.

Since 1937, at least 13 species of anurans have been introduced to Guam, six of which are known to have breeding populations. Eight species were reported for the first time from Guam between 2003 and 2005 (Christy et al. 2007a, b). The probable areas from which anuran species originated include Hawaii, Asia, Australia, the Philippines, and the continental United States. *Rhinella marina* is the only anuran that was intentionally introduced to Guam. The other species arrived by means of different vectors. Four species (*Kaloula picta*, *K. pulchra*, *Polypedates leucomystax*, and *Litoria fallax*) are known or suspected to have been transported on maritime or air-transport vessels. Two species that have direct development (i.e., with no aquatic tadpole stage) are presumed to have been transported by means of the horticultural trade:

*Eleutherodactylus coqui* (not established) and *E. planirostris* (established). Specimens of *Pseudacris regilla* were recovered from shipments of Christmas trees and other agricultural products (it is also appropriate to note that other non-anuran amphibians [newts and salamanders] have reached Guam by means of this vector; D. Vice, DAWR, oral commun., 2010).

Analysis of commerce for the aquarium trade and for aquaculture suggested that the most likely means of introduction of five species, all of which are established on Guam, was by means of the aquaculture sector: *Fejervarya cancrivora*, *F. limnocharis*, *Microhyla pulchra*, *Polypedates megacephalus*, and *Rana guentheri* (Christy et al. 2007b). Most, if not all, of the introductions suspected to be associated with aquaculture likely arrived as unintended contaminants of broodstock fish or other aquaculture species, although the possibility of illegal introductions for use in the food trade cannot be dismissed.

Christy et al. (2007b) considered horticulture and aquaculture to be the primary pathways of concern for frogs arriving to Guam and potentially being disseminated to other Pacific islands. For these pathways, the life-history attributes of frogs may predispose them differentially to transport mechanisms and establishment success. Species without an aquatic larval stage may be readily transported as either eggs or adults in the absence of standing water (e.g. with horticultural products). Species with a tadpole stage could be transported in water (as eggs or larvae) as part of the transport vector (e.g., by means of the pet trade or aquaculture), and some of these could also be transported as adults on non-aqueous materials.

The Animal and Plant Health Inspection Service (APHIS) terrestrial wildlife team prepared a detailed risk assessment for nonindigenous frogs, other amphibians, and selected aquatic or semi-aquatic reptiles of greatest concern (USDA-APHIS 2010). In that assessment, the pet and food trade were identified as pathways of high risk for these taxonomic groups.

## Reptiles

At least six species or subspecies of turtles that normally inhabit freshwater habitats have been introduced to Micronesia; most are confirmed as established on at least some islands (Table 13) (Leberer 2003). Mechanisms of introduction are varied; at least one species (*Pelodiscus sinensis*) was intentionally imported for food by means of the aquaculture pathway, whereas most others were likely released or escaped pets. Additionally, specimens of the terrestrial three-toed box turtle (*Terrapene carolina triunguis*), a species native to the southeastern continental United States, have been observed on Guam (McCoid 1992; Leberer 2003).

The most widespread nonindigenous turtle in Micronesia is the red-eared slider (*Trachemys scripta elegans*), a freshwater taxon native to the southern United States and subspecies of a species broadly distributed in the western hemisphere. The red-eared slider has become one of the most widespread reptiles in the world, largely as a result of its popularity, abundance, and broad dissemination in the pet trade (Lever 2003; Kraus 2009a). The first appearance of the red-eared slider in inland habitats on Guam is not clearly documented. Lever (2003), citing McCoid (1992) and Eldredge (1994), noted that it was first recorded from the municipality of Mangilao in 1991. However, McCoid (1999) speculated that it may have been introduced to Guam as early as the 1950s, whereas Leberer (2003) stated that this turtle may have been introduced to the island in the 1970s. Whether the authors were distinguishing between imported turtles versus occurrence in the wild is uncertain. Currently, the red-eared slider is common in the wild throughout southern Guam, is regularly sold and traded as a pet, and even “used as prizes at island fiestas” (Leberer 2003). In addition to Guam, the red-eared slider is known from Lake Susupe on Saipan, where its status is uncertain (McCoid 1992; McKagan et al. 2009). A single specimen of this turtle subspecies was captured in the wild (at a dump site) on Pohnpei in 1997, without evidence of establishment (Buden 2000; Buden et al. 2001c). The red-eared slider has been present on the Hawaiian island of Oahu since 1980 where it is established in both lotic and lentic habitats (Devick 1991).

The Chinese softshell turtle (*Pelodiscus sinensis*; formerly known as *Trionyx sinensis sinensis*) was imported from Taiwan to Guam for aquaculture (FitzGerald 1982; Eldredge 1994; Leberer 2003; Lever 2003). The commercial venture to produce turtles for food failed within a year, and the surviving stock was either deliberately released or accidentally escaped. The species is now established in central and southern Guam (McCoid 1993; Eldredge 1994; Leberer 2003; Lever 2003).

There are reports, many unconfirmed, of other aquatic or semi-aquatic freshwater turtles from Guam, including common snapping turtle (*Chelydra serpentina*), Reeve’s turtle (*Mauremys reevesii*), Chinese stripe-necked turtle (*Mauremys sinensis*), and a mud turtle of the genus *Kinosternon*. These are presumed to have been pets that either accidentally escaped or were intentionally released (Leberer 2003); their status is unknown, and additional surveys are needed to determine if breeding populations exist on the island. A few other freshwater turtles are established or have been reported on other Pacific islands. For example, the wattle-necked softshell turtle (*Palea steindachneri*) is established on the Hawaiian islands of Kauai and Oahu (Yamamoto and Tagawa 2000; Ernst and Lovich 2009).

Possible negative ecological or economic consequences resulting from the presence of nonindigenous populations of freshwater turtles on Micronesian islands have not been fully assessed. However, based on what is known about the natural diets of the taxa involved, their presence in island inland waters could pose threats to native freshwater fishes and invertebrates (Lever 2003).

Table 12. Nonindigenous aquatic and semi-aquatic anurans (frogs and toads) introduced to Guam and other islands of Micronesia. [CNMI, Commonwealth of the Northern Mariana Islands; FSM, Federated States of Micronesia]

| Family | Species | Common name[a] | Location | Status | Notes | Reference(s) |
|---|---|---|---|---|---|---|
| Bufonidae | *Rhinella marina* (Linnaeus 1758) | cane toad | FSM (Chuuk, Kosrae, Pohnpei, Yap) | Established | | Buden (2007) |
| | | | Palau | Established | | Crombie and Pregill (1999) |
| | | | Guam | Established | | Rodda et al. (1991); Christy et al. (2007a,b) |
| | | | CNMI | Established | | Rodda et al. (1991) |
| Dicroglossidae | *Fejervarya cancrivora* (Gravenhorst 1829) | crab-eating frog | Guam | Unknown | | Christy et al. (2007a,b) |
| | *Fejervarya limnocharis* (Gravenhorst 1829) | alpine cricket frog | Guam | Established | | Christy et al. (2007a,b) |
| Eleutherodactylidae | *Eleutherodactylus coqui* Thomas 1966 | Coqui | Guam | Not established | Direct development (no aquatic larval stage) | Christy et al. (2007a,b) |
| | *Eleutherodactylus planirostris* (Cope 1862) | greenhouse frog | Guam | Established | Direct development (no aquatic larval stage) | Christy et al. (2007a,b) |
| Hylidae | *Litoria fallax* (Peters 1880) | eastern dwarf treefrog | Guam | Established | | Rodda et al. (1991); Eldredge (2000); Christy et al. (2007a,b); |
| | | | Saipan | Unknown | No voucher; call heard by wildlife biologist | Rodda et al. (1991) |
| | *Pseudacris regilla* (Baird & Girard 1852) | Pacific treefrog | Guam | Not established | | Christy et al. (2007a,b) |
| Microhylidae | *Kaloula picta* (Duméril & Bibron 1841) | slender-digit chorus frog | Guam | Not established | | Christy et al. (2007a,b) |
| | *Kaloula pulchra* Gray 1831 | Asian painted frog | Guam | Not Established | | Christy et al. (2007a,b) |

Table 12. Nonindigenous aquatic and semi-aquatic anurans (frogs and toads) introduced to Guam and other islands of Micronesia. [CNMI, Commonwealth of the Northern Mariana Islands; FSM, Federated States of Micronesia]

| Family | Species | Common name[a] | Location | Status | Notes | Reference(s) |
|---|---|---|---|---|---|---|
| | *Microhyla pulchra* (Hallowell 1861) | beautiful pygmy frog | Guam | Unknown | | Christy et al. (2007a,b) |
| Ranidae | *Rana guentheri* Boulenger 1882 | Günther's amoy frog | Guam | Established | | Christy et al. (2007a,b) |
| Rhacophoridae | *Polypedates leucomystax* (Gravenhorst 1829) | Asian brown tree frog | Guam | Not established | | Christy et al. (2007a,b) |
| | *Polypedates megacephalus* Hallowell 1861 | Hong Kong whipping frog | Guam | Established | | Christy et al. (2007a,b) |

[a] Many different common names are in use; see APHIS (2010) for complete list for most species.

Table 13. Nonindigenous aquatic and semi-aquatic reptiles introduced to Micronesia.

| Family | Species | Common Name | Location | Status | Notes | Reference(s) |
|---|---|---|---|---|---|---|
| Bataguridae | *Mauremys* (*Chinemys*) *reevesii* (Gray 1831) | Reeve's turtle; three-keeled pond turtle | Palau | Unknown | Species identification not confirmed (no voucher available) | Crombie and Pregill (1999) |
| | | | Guam | Not established | One record only, animal was in captivity in 2003 | Leberer (2003) |
| | *Mauremys* (*Ocadia*) *sinensis* (Gray 1834) | Chinese stripe-necked turtle | FSM (Pohnpei) | Not established | One record only, specimen collected | Buden et al. (2001c) |
| | | | Guam | Unknown | Breeding status unknown | Leberer (2003) |
| Chelidae | Chelidae, genus and species undetermined | | Palau | Unknown | No voucher specimen | Crombie and Pregill (1999) |
| Chelydridae | *Chelydra serpentina* (Linnaeus 1758) | common snapping turtle | Guam | Unknown | Breeding status unknown | Leberer (2003) |
| Emydidae | *Trachemys scripta elegans* (Wied-Neuwied 1839) | red-eared slider | FSM (Pohnpei) | Not established | One record only, animal was in captivity in 2001 | Buden (2000); Buden et al. (2001c) |
| | | | Guam | Established | | Leberer (2003) |
| | | | Saipan | Unknown | Breeding status unknown, but likely established | Rodda et al. (1991) |
| Kinosternidae | *Kinosternon* sp. Spix 1824 | mud turtle | Guam | Not established | One record only in published literature (animal was in captivity in 2003); unverified specimen observed for sale in 2010 by roadside vendor (E. Wostl, USGS, oral commun., 2010) | Leberer (2003) |
| Trionychidae | *Pelodiscus sinensis* (Wiegmann 1834) | Chinese softshell | Guam | Established | | Leberer (2003) |

## Fishes

A wide variety and large numbers of nonindigenous fishes have been introduced to freshwater habitats in Micronesia and other islands of Oceania. As a result, nonindigenous fishes are common on most islands in the region that have freshwater environments. In many areas nonindigenous fishes are the most abundant and visible group of introduced aquatic animals. Several publications have synthesized global or regional information on the distribution of nonindigenous fishes and other nonindigenous aquatic organisms. Most include annotated listings or accounts of species introduced to Micronesia or to specific island groups (Welcomme 1981; Maciolek 1984; Welcomme 1988; Nelson and Eldredge 1991; Munro 1993; Eldredge 1994, 2000). Additionally, databases exist that track distributional records of introduced species as reported in the literature or from other sources (Casal 2006; Froese and Pauly 2011). Hawaii has also had numerous introductions and establishment of freshwater fishes (Maciolek 1984; Devick 1991; Eldredge 1994; Yamamoto and Tagawa 2000; Mundy 2005). Some fishes were intentionally transported among many different Pacific islands, island groups, and mainland areas (e.g., Southeast Asia) and for many different reasons. For example, Nelson and Eldredge (1991) and Eldredge (1994) summarized intentional tilapia introductions to Pacific islands with putative sources and reasons for introduction, where known.

At least 25 nonindigenous freshwater or catadromous fish species or taxa have been introduced into the waters of Guam. Of these, 13 are known to be established (Tables 14-15). The source of these introductions is varied. Some species were intentionally stocked on Guam, especially in the Fena Reservoir and the Talofofo River, for sport fishing, as biological control agents, or both (e.g., *Oreochromis mossambicus*, *Micropterus salmoides*, *Cichla ocellaris*, *Ictalurus punctatus*, *Gambusia affinis*) (Brock and Takata 1956). Some species were initially held in aquaculture facilities and dispersed to inland waters and/or their spread was augmented by humans (e.g., *Clarias batrachus*, *Oreochromis mossambicus*, *Tilapia zillii*, and *Channa striata*). Other species may have been releases of aquarium fishes (e.g., *Betta pugnax*, *Astronotus ocellatus*, and *Poecilia reticulata*). Agana Springs and the adjacent marsh and swamp habitats are sites where aquatic pets and other nonindigenous species have been released or spread to (Randall et al. 1974; B. Tibbatts, DAWR, pers. comm.).

A recent survey for nonindigenous species on Saipan resulted in documentation of at least four different taxa of introduced fishes (McKagan et al. 2009) (Fig. 12; Tables 16, 17). Overall fish species richness at sites on Saipan was low, with most sites having two species or less. Moreover, native species appeared to have been displaced by nonindigenous species at disturbed sites.

In comparison to other island groups of the western and central Pacific (e.g., Hawaii and Fiji), there have been relatively few freshwater fish species introduced to Micronesian islands with the exception of Guam. Certain species or taxonomic groups (e.g., tilapiine cichlids and mosquitofishes) have been broadly introduced and in some areas have spread locally. In general there may have been fewer fish introductions from west to east in the Carolines. At least five different nonindigenous fish species have been reported from inland waters of Palau (Table 10) (Bright and June 1981; Eldredge 2000; our own surveys). The most recent fish introduced to Palau was the Mozambique tilapia (*Oreochromis mossambicus*), to which the government responded by attempting to eradicate several localized populations that were discovered, in an effort that was partially successful (Nico and Walsh, in press). To date only two nonindigenous freshwater fish species (*O. mossambicus*, *Gambusia affinis*) are known from Pohnpei (B. Lynch and D. Buden, oral commun., 2010). A single species (*O. mossambicus*) has thus far been reported from Yap (Nelson and Hopper 1989).

Table 14. Nonindigenous freshwater fish species introduced to Guam. [Status codes: E = established in inland waters of Guam; NE = not established or insufficient information available. Known or presumed pathway of introduction: A = aquaculture (escapement or intentional release); S = stocked for sport fishing, biocontrol, and/or as forage; O = ornamental. Sources of data include Maciolek (1984), Eldredge (2000), and B. Tibbatts (DAWR, written commun., 2010)]

| Status | Family | Scientific name | Common name | Source |
|---|---|---|---|---|
| NE | Anguillidae | *Anguilla bicolor pacifica* Schmidt 1928 | Japanese eel | A |
| NE | | *Anguilla rostrata* (Lesueur 1817) | American eel | A |
| NE | Ariidae | *Arius* sp. Valenciennes 1840 | sea catfish | A? |
| NE | Centrarchidae | *Micropterus dolomieu* Lacepède 1802 | smallmouth bass | S |
| NE | | *Micropterus salmoides* (Lacepède 1802) | largemouth bass | S |
| NE | Centropomidae | *Lates calcarifer* (Bloch 1790) | barramundi | A |
| E | Channidae | *Channa striata* (Bloch 1793) | chevron snakehead | A |
| E | Cichlidae | *Astronotus ocellatus* (Agassiz 1831) | oscar | O |
| E | | *Cichla ocellaris* ? Bloch & Schneider 1801[a] | peacock cichlid | S |
| E | | *Oreochromis mossambicus* (Peters 1852) | Mozambique tilapia | S |
| NE? | | *Tilapia rendalli* (Boulenger 1897)[b] | redbreast tilapia | S |
| E | | *Tilapia zillii* (Gervais 1848) | redbelly tilapia | S |
| E | Clariidae | *Clarias batrachus* (Linnaeus 1758) | walking catfish | A |
| E | | *Clarias macrocephalus* Günther 1864 | bighead catfish | A |
| NE | Cyprinidae | *Ctenopharyngodon idella* (Valenciennes 1844) | grass carp | A |
| E | | *Cyprinus carpio* Linnaeus 1758 | common carp, koi | O,S |
| NE | | *Hypophthalmichthys nobilis* (Richardson 1845) | bighead carp | S |
| NE | | *Puntius lateristriga* (Valenciennes 1842) | spanner barb | O |
| NE | Ictaluridae | *Ictalurus punctatus* (Rafinesque 1818) | channel catfish | S |
| E | Osphronemidae | *Betta pugnax* (Cantor 1849) | Penang betta | O |
| NE | Pangasiidae | *Pangasianodon hypophthalmus* (Sauvage 1878) | iridescent shark-catfish | A? |
| E | Poeciliidae | *Gambusia affinis* (Baird & Girard 1853) | eastern mosquitofish | S |
| E | | *Poecilia latipinna* (Lesueur 1821) | sailfin molly | O |
| E | | *Poecilia reticulata* Peters 1859 | guppy | O,S |
| E | | *Xiphophorus hellerii* Heckel 1848 | green swordtail | O |
| NE | | *Xiphophorus maculatus* (Günther 1866) | southern platyfish | O |

[a] In early reports the *Cichla* species introduced to Guam was identified as *C. ocellaris*; however, over recnt years the genus *Cichla* has been extensively revised, calling into question the identity of introduced populations.

[b] Nomenclature/taxonomy in question; some authors place in synonymy with *T. melanopleura*. Eldredge (2000) listed this taxon as established in Guam, but Maciolek (1984) did not.

Table 15. Distribution of established (reproducing) nonindigenous freshwater fishes on Guam by drainage (DAWR data courtesy of B. Tibbatts).

| **Drainage** | ***Channa striata*** | ***Cichla ocellaris*** | ***Clarias batrachus*** | ***Cyprinus carpio*** | ***Gambusia affinis*** | ***Oreochromis mossambicus*** | ***Poecilia reticulata*** | ***Tilapia zillii*** | ***Xiphophorus hellerii*** | **Total Species** |
|---|---|---|---|---|---|---|---|---|---|---|
| Agana | | | X | X | X | X | X | X | | 6 |
| Agfayan | | | | | X | X | | | | 2 |
| Ajayan | X | | | | X | X | | | | 3 |
| Almagosa | | X | | | X | X | | X | | 4 |
| Aplacho | | | | | | | X | | | 1 |
| Asalonso | | | | | | X | | | | 1 |
| Asan | | | | | | X | | | | 1 |
| Atantano | | | | | X | | X | | | 2 |
| Big Guatali | | | | | | X | | | | 1 |
| Chaligan | | | | | | X | | | | 1 |
| Chaot | | | X | X | X | X | X | X | | 6 |
| Finile | | | | | | | X | | | 1 |
| Fonte | | | | | | X | X | | | 2 |
| Geus | | | | | X | X | | | | 2 |
| Guatali | | | | | | | X | | | 1 |
| Imong | | X | | | X | X | X | X | | 5 |
| Inarajan | | | | | X | X | | | | 2 |
| Laguas | | | | | | | X | | | 1 |
| Lonfit | | | | | | X | | X | | 2 |
| Maagas | | X | X | | | X | | X | | 4 |
| Manenggon | | | | | | X | | X | | 2 |
| Masso | | | X | | X | X | X | | | 4 |
| Maulap | | X | | | | X | | X | | 3 |
| Namo | | | | | | X | X | | | 2 |
| Pago | | | | | X | X | | X | | 3 |
| Sadog | | X | | | X | X | X | X | | 5 |
| Salinas | | | | | | | X | | | 1 |
| Sasa | | | | | | X | | | | 1 |
| Small river on Mt. Santa Rosa | | | | | X | | X | | | 2 |
| Talofofo | | X | X | | X | X | | | | 4 |
| Tarzan | | | | | | | X | | X | 2 |
| Tinechong | | | X | | | | X | | | 2 |
| Togcha (E) | | | | | | X | X | | | 2 |
| Tolaeyuus | | | X | | | | | | | 1 |
| Ugum | | | | | X | X | | | | 2 |
| Unnamed stream - tributary to Ugum | | | X | | | X | | | | 2 |
| Ylig | | | | | | X | | X | | 2 |
| **Total drainages** | 1 | 6 | 8 | 2 | 15 | 27 | 17 | 11 | 1 | |

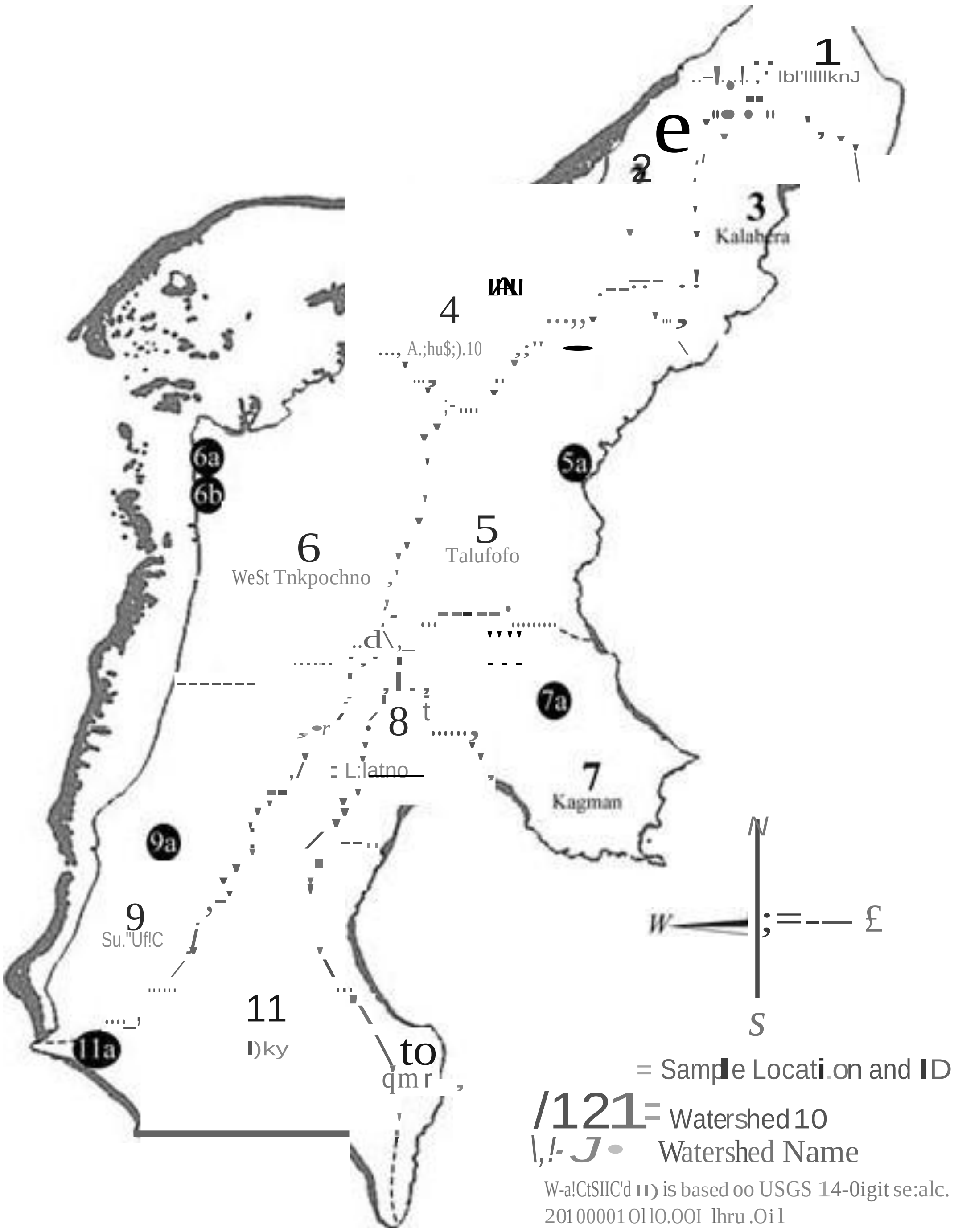


Figure 12. Watersheds of Saipan and sampling s es of species surveyed by Commonweah of the Northem Manana Islands (CNMI) Dillision of Fish and Widlife (MeKagan et al. 2009). See Table 16 for site geocoordinates.

Table 16. Freshwater sites on Saipan sampled for aquatic organisms by CNMI Division of Fish and Wildlife, with station numbers, names, and geocoordinate of each site (McKagan et al. 2009). [See Fig. 12 for location of sites; CNMI, Commonwealth of the Northern Mariana Islands]

| Site no. | Site | Geocoordinates |
|---|---|---|
| 2a | MCC Golf Course, Pond at Hole #6 | 15°15.75´N 145°47.69´E |
| 3a | DPS Gun Range, Marsh | 15°14.27´N 145°47.373´E |
| 4a | Tanapeg, Bobo Achugao Stream | 15°14.183´N 145°45.798´E |
| 5a | Jeffry's Beach Stream | 15°12.97´N 145°46.772´E |
| 5b | Tegata's Upper Stream | 15°13.811´N 145°46.35´E |
| 6a | Garapan Slough at Fiesta Hotel | 15°12.785´N 145°42.992´E |
| 6b | Garapan Slough at Hafa Adai Hotel | 15°12.493´N 145°42.983´E |
| 7a | Kagman Mitigation Ditch | 15°10.426´N 145°46.069´E |
| 7b | Kagman Shrine, Upper Stream | 15°10.915´N 145°45.828´E |
| 9a | Lake Susupe | 15°9.171´N 145°42.609´E |
| 9b | Costco Marsh | 15°10.227´N 145°42.833´E |
| 11a | COP Golf Course, Pond at Hole #5 | 15°7.181´N 145°41.785´E |

Table 17. Aquatic and semiaquatic animal species collected at freshwater sites on Saipan (McKagan et al. 2009). [See Table 16 and Fig. 12 for station information. Nonindigenous taxa indicated by shaded cells. A, anecdotal; S, surveyed; O, observed]

| Class or Order | Taxon | Station | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2a | 3a | 4a | 5a | 5b | 6a | 6b | 7a | 7b | 9a | 9b | 11a |
| Gastropoda | Planorbidae | | S | | | | | | | | S | S | |
| | Ampullariidae | | | | | | | | | | S | S | |
| | Thiaridae | | | | | | S | S | | S | | S | |
| Decapoda | *Caridina typus* | | | | S | S | | | | S | | | |
| | *Macrobrachium lar* | | | S | S | S | | | | S | | | |
| | *Palaemon concinnus* | | | | | | | | | | S | | |
| Osteichthyes | *Anguilla* sp. | | | A | | | | A | | A | | | |
| | *Chanos chanos* | | | | | | S | S | | | | | |
| | *Eleotris acanthopoma* | | | | | | | S | | | | | |
| | *Gambusia affinis* | | | | | | | | | | S | | |
| | *Kuhlia rupestirs* | | | | S | | | | | | | | |
| | *Megalops cyprinoides* | | | | | | | S | | | | | |
| | *Oreochromis* spp. | S | | | | | S | O | | | S | O | S |
| | *Poecilia latipinna* | | | | | | S | S | | | S | | |
| | *Poecilia reticulata*[a] | | | | | | | | | | | | |
| | *Stiphodon elegans* | | | | S | O | | | | | | | |
| Amphibia | *Rhinella marina* | | S | | | | | | S[b] | | | S[b] | |
| Reptilia | *Trachemys scripta elegans* | | | | | | | | A | | A | | |

[a]Lumped with *P. latipinna* by McKagan et al. (2009).

[b]All tadpoles collected were presumed to be *R. marina*, since no other amphibians have been reported from Saipan.

## Pathways of Introduction

Increased rates of international trade, travel, and transport over recent decades have led to widespread introductions and frequent mixing of biotas from across the world (Pyšek et al. 2010). Introductions of nonindigenous species to new locations typically occur by means of three main mechanisms: importation of a commodity, arrival of a transport vector, or dispersal of previously introduced populations (Hulme et al. 2008). Pathways are defined here as the general route or activity by which a species can be introduced into a new locale whereas vectors are considered to be the specific mechanism, mode, or activity associated with that introduction. Often, individual species are introduced through multiple combinations of vectors and pathways.

The following types of pathways are the most common means by which freshwater animals (and plants) are introduced to inland areas outside of their natural ranges (Fuller et al. 1999; Nico and Fuller 1999; Kolar and Lodge 2002; Helfman 2007; Leung and Dudgeon 2008; Kolar et al. 2011):

- Releases of live animals previously maintained in aquaria, water gardens, and so forth (i.e., the ornamental pet trade)
- Escape from aquaculture or holding facilities
- Transport and release associated with the live-food industry
- Legal stocking, typically by government agencies (purposes may be varied; for example, to establish game or forage species, for biocontrol, for conservation of rare species, or for research or experimental purposes)
- Illegal or unauthorized stocking
- Bait-bucket release
- Transport and release through vessel ballast water, as hull-fouling organisms, or unintentional contaminants associated with other vectors
- Habitat modification (e.g., canals or artificial waterways that connect previously unconnected water bodies)
- Natural causes that aid in the dispersal of already existing nonindigenous populations (e.g., typhoons, transport by animals other than humans)

Regional patterns of invasion are complex, and shaped by a wide range of factors that vary over space and time (Pyšek et al. 2010). Over the years there has been an increasing number of studies published on pathways and the relative role that each has played in the establishment of nonindigenous aquatic species. Given the extensive and growing amount of literature on the subject, the list just presented should not be considered all-inclusive. Additional information about the role of selected pathways in the establishment of freshwater species in Micronesia is provided in the *Existing Conditions* sections of the *Management Alternatives* of this document.

Based on existing evidence, pathways that have contributed greatly to the introduction of nonindigenous freshwater fishes into inland waters of Micronesia—and that will likely remain a threat in the near future—include (1) intentional or unintentional releases associated with the ornamental species trade, (2) escape from aquaculture facilities, and (3) releases associated with the live food industry. Certain other pathways (e.g., ballast water, bait-bucket releases) appear to have posed little threat historically and presumably will present low relative risk in the future. However, other pathways (e.g., contaminants in other stocks) may currently and/or in the future pose relatively high risk, yet are inadequately documented and difficult to evaluate. Most threats are not mutually exclusive, and may act synergistically to increase risk.

## Mechanisms of Spread

When a nonindigenous species becomes introduced into a novel environment, there are many factors that contribute to whether or not it will become established and the degree to which it will spread if established. An exhaustive review of these factors is beyond the scope of this study. However, a few generalizations provide insight into characteristics of aquatic species that contribute to their success at becoming established, and to some extent, the degree to which they spread or become invasive.

Ehrlich (1986; 1989) listed the following characteristics that are common to many species that successfully become established when introduced to places where they are not native:

- Large native range
- Abundant in native range
- Vagile
- Short generation time
- High genetic variability
- Gregarious
- Female able to colonize alone
- Larger than most relatives
- Broad diet
- Able to function in a wide range of physical conditions
- Associated with humans

As noted by Eldredge (2000), many of the nonindigenous freshwater species established on Pacific islands exhibit combinations of these characteristics, although one exception is body size, because most species introduced to these insular areas are relatively small.

Helfman (2007) examined these factors in more detail for fishes, and, drawing on selected literature sources, summarized the characteristics that favored successful invaders, characterized invasible habitats, and contrasted the first with opposing characteristics of vulnerable native species (Tables 18-19). Notably, many of the traits listed by Helfman (2007) are identical to those listed by Ehrlich (1986; 1989), thus indicating certain common factors across taxonomic groups and ecosystems. Many authors have invoked such species characteristics to analyze and attempt to better understand establishment and invasion success. Moreover, different factors may operate and affect success differentially and in unique combinations of ways during different stages of the invasion process (Kolar and Lodge 2001; Kolar and Lodge 2002). Some of these factors are addressed in greater detail in our risk analysis of establishment success for freshwater fishes introduced to Hawaii and Guam (see *Risk Assessment and Analysis*).

Table 18. General characteristics of successful fish invaders; see Helfman (2007) and references therein. [Different traits may affect success at different stages of invasion. Vulnerable native species were considered by the author to have characteristics contrasting to those indicated by asterisks]

| Characteristic(s) |
|---|
| High reproductive rate; including high fecundity, short interbreeding interval* |
| Short generation time with rapid maturation* |
| Long-lived with rapid maturation |
| High dispersal rate* |
| "Pioneer" species; good colonists (with r-selected life-history traits)* |
| Biparental care unnecessary |
| Broad native range* |
| Abundant in native range* |
| High genetic variability and phenotypic plasticity* |
| Tolerant of wide range of water-quality criteria* |
| Ecological generalist with respect to habitat and trophic requirements (piscivores, detritivores, herbivores, some planktivores most successful)* |
| Previous history of successful invasions by the species or close relatives |
| Gregarious |
| Ability to breathe air |
| Medium body size; large size advantageous for predators |
| Human commensal |

Table 19. General characteristics of highly invasible habitats and communities, after Helfman (2007).

| Characteristic(s) |
|---|
| Human-modified habitat; such as with altered flow regime, impoundment, channelization, sedimentation, deforestation of riparian and uplands, urbanization, pollution |
| Decreased natural variability in hydrology or geomorphology |
| Relatively benign and physicochemically stable habitats, as opposed to those with extreme fluctuations (however, exceptions exist in which certain invaders may be more likely to become extirpated under such extremes) |
| Assemblages with vacant trophic representation, such as few or no predators or zooplanktivores |
| Low-diversity assemblages |
| Insular streams and lakes |
| Highland lakes |
| Tropical rivers |

## Existing Legislative and Regulatory Framework

Regulations governing the importation, stocking, and possession of nonindigenous species vary widely among different nations, states, and government agencies. Within the United States, more than 20 Federal agencies, as well as many State and local agencies are involved in the management of undesirable or invasive aquatic organisms (Kolar et al. 2011). The U.S. Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 provided a strategic framework, through the establishment of an interagency committee, to coordinate and prioritize efforts and programs designed to control and manage aquatic nuisance species in U.S. waters. Federal efforts in the United States are coordinated by the National Invasive Species Council (NISC), established in 1999. A National Invasive Species Management Plan (NISC 2001, 2008) provides the guidelines for Federal agencies to engage authorities and coordinate existing programs to prevent introductions and spread of invasive species, apply rapid detection and response actions, mitigate for impacts, and restore native species and habitats. In practice, however, most fisheries management efforts for nuisance species in inland waters of the United States and its possessions are jointly administered across administrative levels, and for some activities done primarily at the local or state level. This general topic was reviewed by Kolar et al. (2011), who summarized some of the basic measures that management agencies invoke to prevent or reduce consequences of introductions (Table 20). There are also several international instruments that are available to Micronesian governments. These include binding international agreements (e.g., 1992 Convention on Biological Diversity) and guidelines to minimize the spread of non-native freshwater species (e.g., EIFAC Code of Practice for recreational Fisheries [EIFAC, 2008]).

Table 20. Common vectors by which nuisance fishes and other aquatic species are commonly introduced to inland waters, and methods used to minimize risks associated with intentional introductions (stocking by government agencies) or to minimize introduction events (all other vectors) within the United States (from Kolar et al. 2011). [Asterisk represents more common level of regulation.]

| | Prevention measures | | |
|---|---|---|---|
| **Vector of introduction** | **Regulation** | **Management Options** | **Education and outreach** |
| Ballast water | Federal*, State | X | |
| Aquaculture industry | Federal, State* | X | |
| Live food fish industry | Federal, State* | X | X |
| Stocking by government agencies | Federal, State* | X | X |
| Water garden and aquarium pets | Federal, State* | | X |
| Unauthorized stocking | Federal, State* | | X |
| Bait-bucket releases | State | | X |
| Recreational activities | State | X | X |
| Research activities | State | X | X |
| Diffusion from neighboring waters | | | X |

Initially, we attempted to review the legislative authorities and the existing regulatory framework governing management for nuisance freshwater species in Micronesia. However, the information obtained is incomplete because of the large number of different states and island nations, the complex nature of the subject, apparent or likely changes in regulations over time, and difficulty in obtaining verifiable data. Nevertheless, a brief summary of some of the relevant information obtained during the course of this study provides a basis for understanding how regional governments apply and administer rules and regulations designed to manage for invasive species. Most of this information is directly applicable to the primary pathways of interest in this document; that is, the pet trade, aquaculture, intentional stocking programs, and live-food animal trade.

## Hawaii

The legislative and administrative policies for Hawaii have direct relevance to Micronesia due to the extensive trade of live animal and plant commodities across the Pacific. The Hawaiian Department of Agriculture (HDOA) maintains a web site (*http://hawaii.gov/hdoa*) that provides extensive information about regulations of the State of Hawaii governing the import and export of organisms by means of the live animal and plant trade. Most of the regulations, practices, and other management factors are similar for the individual types of trade involving aquatic species (i.e., common to the pet, live or fresh food, ornamental, bait, and aquaculture trades). HDOA requirements that pertain to the importation of live animals for food generally emphasize nonaquatic organisms, specifically, domesticated livestock and other species. Hawaii's Administrative Rules establish the guidelines, limitations and parameters for specific types of actions within the context of the Hawaii Revised Statutes (*http://hawaii.gov/hdoa/admin-rules*). Certain types of animals, insects, microorganisms and plants are not allowed entry to Hawaii. For those that are allowed, import permits, letters of authorization, quarantine and/or health certificates may be required. A few examples of animals that are prohibited from importation or possession by private individuals in Hawaii include the following: alligators, bearded dragon lizards, coconut crabs, electric catfishes, hermit crabs, land snails, lionfishes, piranhas, snakes, and snapping turtles. All freight companies transporting agricultural items to Hawaii must notify a Plant Quarantine Inspector of these items and insure that all items, including cargo and mail, are available until the inspection is completed. The HDOA's Plant Quarantine Branch conducts pre-entry, entry, and post-entry inspections of regulated materials entering the State. All microorganisms and nondomestic animals and certain microorganisms and plants require permits prior to their importation.

## Guam

Codified laws of Guam regulating the importation, care, conservation, and use of fish and wildlife are provided by the Guam Administrative Rules and Regulations, Title 9 (as of April 2004), available online at: *http://www.justice.gov.gu/compileroflaws/GAR/09gar.html*. Most of these laws apply to domesticated livestock and feral animals. Rules governing aquatic organisms are generally listed under Title 9, Division 2 (Conservation, Hunting & Fishing Regulations), Chapter 12, Fishing Regulations. The General Guam Administrative Rules and Regulations home page is: *http://www.justice.gov.gu/compileroflaws/gar.html*. The Guam Division of Aquatic and Wildlife Resources (DAWR) maintains a white list of permitted plants and animals; any animals or plants not present on the white list are prohibited from importation, but there is no existing legislation to prohibit possession of species not on the white list. The DAWR issues permits for the importation of any aquatic organism and requires scientific name, common name, number requested, point of origin, shipper, and receiving party. U.S. Customs maintains documents showing the number of organisms actually received. The DAWR does not allow the importation of any reptiles or amphibians. Freshwater fishes are permitted for the pet trade and for aquaculture. No fishes are currently allowed to be imported for biocontrol, bait, or sport purposes.

In Guam, the U.S. Department of the Interior, Law Enforcement Division, Fish and Wildlife Services (USFWS), has responsibility pertaining to the importation of reptiles, fish, and endangered species. A license is required for commercial imports or exports of fish and wildlife and/or their parts and products into or out of the United States and importers are also required to file a Declaration for Importation or Exportation of Fish or Wildlife (Form 3-177) at an authorized port of entry to receive clearance before U.S. Customs releases the shipment. Live aquatic animals and other wildlife are monitored through a system of national ports designated and managed by the USFWS Office of Law Enforcement, U.S. Customs Service (USCS), and the U.S. Department of Agriculture (USDA).

The most detailed records pertaining to imports of live aquatic animals are those in the USFWS Law and Enforcement Management Information System (LEMIS). The USFWS compiles much of the information from U.S. Customs shipment declaration forms. Shipment records in LEMIS include information on number or weight of animals per container, scientific name, intended purpose, source, and country of origin; records are discarded every six years. Some data do not distinguish freshwater from marine species, and not all import declaration forms indicate source. Moreover, the country of origin is not always known with certainty because transshipments are common. Inadequate record keeping at ports makes it difficult to fully assess the diversity of live fishes imported, thereby hindering risk analysis and prevention programs.

### Commonwealth of the Northern Mariana Islands

Codified laws of the CNMI are maintained by the Commonwealth Law Revision Commission (*http://www.cnmilaw.org/welcome.php*). The complete CNMI Administrative Code was not available to the authors. Regulations governing the importation of wildlife, permitting, law enforcement, and other management issues are under the jurisdiction of the CNMI Division of Fish and Wildlife (DFW): *http://www.dfw.gov.mp/Enforcement/Fishing%20Regulations.html*. The DFW enforcement section reviews all live imports, and often, dead, frozen imports. The DFW currently uses an Australian Quarantine and Inspection Service list to determine which species of fish to automatically admit and which to send for a more formal review by DWF biologists (S. McKagan, National Marine Fisheries Service, oral commun., 2010).

### Federated States of Micronesia

The FSM National Government laws are summarized in the FSM Legal Information System: *http://www.fsmlaw.org/fsm/index.htm*. The FSM maintains official Plant & Animal Quarantine Regulations, which were not obtained during the course of this project. According to FSM law (Title 19, Chapter 4, Section 19.414), "No person shall export or import any live fish or viable fish eggs without the Director's prior written permission."

### Republic of Palau and Other Micronesian Islands

Codified laws for Palau regarding importation, transport, distribution, or possession of nonindigenous aquatic species were not obtained. Likewise, no effort was made to obtain administrative rules and policies for those Micronesian islands or island groups with no significant freshwater resources.

# Risk Assessment and Analysis

## Introduction

Risk assessments are useful for estimating the risks associated with introductions of nonindigenous species. For instance, a risk assessment can be used to predict the likelihood that a particular nonindigenous species, if introduced, may become established and to what degree it may be invasive or cause ecological or economic harm (Pheloung et al. 1999; Bomford 2003; Daehler et al. 2004; Kolar 2004; Nico et al. 2005; Bomford 2008; Fujisaki et al. 2009). A variety of risk assessment techniques exist. Some of these methods are largely qualitative in nature; for example, relying on scoring relative values for species traits such as 0 or 1 (absent or present), or 'low/medium/high' (Pheloung et al. 1999; Orr 2003; Alfaro et al. 2009). Some authors have argued for use of more quantitative approaches to reduce subjectivity, more precisely, to identify gaps in knowledge and provide ways to statistically express uncertainty and variability (NRC 2002; Hayes 2003; Lockwood et al. 2007). Both qualitative and quantitative estimations of species-specific risk of establishment success may aid in screening species by identifying species that could be excluded or removed from permitted (white) lists, as well as species that could be considered for addition to prohibited (black) lists (Kolar and Lodge 2001, 2002; Marchetti et al. 2004a, b; Fujisaki et al. 2009; Bomford et al. 2010).

Among the many oceanic islands and archipelagos of the tropical Pacific, Guam is second only to the Hawaiian Islands in the numbers of nonindigenous fish introductions and establishments (Maciolek 1984). Our initial objective was to develop a purely quantitative model of establishment success of freshwater fishes in Guam. However, the number of nonindigenous fishes documented in Guam ($n$ = 25), although large for an island of Oceania, was inadequate to develop a model useful for predictive purposes. To improve the power of the modeling approach to assessing establishment probability, we included data on fishes introduced and established in Hawaii. At least 46 nonindigenous freshwater fish species or taxa are documented as being established in inland waters of the Hawaiian Islands; additional nonindigenous fishes have been introduced, but apparently never formed permanent reproducing populations (Maciolek 1984; Eldredge 1994; Fuller et al. 1999; Yamamoto and Tagawa 2000; Mundy 2005; Nico et al. 2005).

A wide array of life-history traits have been correlated with the establishment and invasiveness of nonindigenous species (Kolar and Lodge 2001, 2002; Marchetti et al. 2004a, b; Bomford 2008; Bomford et al. 2009; Bomford et al. 2010). Blackburn (2009) summarized species traits into three categories related to persistence of small populations. Those authors argued that establishment success should be positively correlated with propagule pressure and with traits related to the ability to cope with novel environments, and correlated in some way with traits related to population growth rate and Allee effects (i.e., the positive correlation between population density and per capita population growth rate). We developed a model of establishment success of nonindigenous fishes in Guam and Hawaii using a set of variables related to propagule pressure, prior establishment success on tropical islands, and species traits. This model may be useful in screening freshwater fishes imported into Guam, Hawaii and other Pacific islands, thereby reducing the probability of additional invasive species becoming established on individual islands and in this region.

### Nonindigenous Fish Taxa Included in Estimation of Establishment Success

For this analysis, nonindigenous fish data for the island of Guam and the Hawaiian islands are combined. Both share similar physiographic and climatic features and are subjected to fish introductions through similar pathways.

A total of 80 different nonindigenous fish taxa representing 33 fish families have been introduced to Guam and the Hawaiian Islands; this total includes species or taxa that are established as well as others that were reported as having been introduced but are not known to have formed permanent reproducing populations (Table 21) (Maciolek 1984; Eldredge 1994; Nico and Fuller 1999; Eldredge 2000; Yamamoto and Tagawa 2000; Mundy 2005). The list is composed mostly of fish recognized as distinct species. In addition, the list also treats as single taxa certain groups of closely related fish (e.g., *Channa striata* and *C. maculatus*; pacus of the genus *Colossoma* and *Piaractus*). This conservative approach was taken because members within these particular groups are very similar in appearance and records of their occurrence in Hawaii or Guam may have been based on incorrect identifications (e.g., recognizing two or more species, when only one species was actually introduced). Of the 80 total nonindigenous fish taxa reported, 70 are recorded from Hawaii and 25 from Guam; 15 nonindigenous fish species are common to both regions.

An established species was defined as any taxon known to have a self-sustaining wild population in either Hawaii or Guam. Included in this analysis are species that are restricted to fresh water, species found in brackish and fresh water (e.g., mangrove goby, *Mugilogobius cavifrons*), and species that occur in marine, brackish, and fresh water (e.g., Gulf killifish, *Fundulus grandis*). Thirteen species identifications were not known with certainty; for these taxa, variables used in the analysis were scored based on the species most likely to have been introduced as evidenced from other introductions (e.g., Maciolek 1984; Fuller et al. 1999; Eldredge 2000; Mundy 2005) or species presumed to share similar life-history and ecophysiological attributes.

Table 21. Status of nonindigenous freshwater fishes known to have been introduced into Hawaii and Guam since the late 1800s (status: 1 = established, defined as a self-sustaining, wild population; 0 = introduced, not known to be established; blank cells indicate species not known to have been introduced into that region). [Species not identified with certainty indicated by use of “cf.”, “?”, “sp ?” or “‘complex.” Thirteen such species of uncertain identification were included among the 80 species used in quantitative risk analysis. Shading indicates air-breathing species; fitted values for best model (#23) of establishment success in risk analysis (see text)]

| Family | Scientific name | Common name | Hawaii status | Guam status | Fitted value |
|---|---|---|---|---|---|
| Adrianichthyidae | *Oryzias latipes* | Japanese medaka | 0 | | 0.060 |
| Anguillidae | *Anguilla japonica* | Japanese eel | | 0 | 0.031 |
| Anguillidae | *Anguilla marmorata* | giant mottled eel | 0 | | 0.031 |
| Anguillidae | *Anguilla rostrata* | American eel | | 0 | 0.031 |
| Anostomidae | *Leporinus fasciatus* | banded leporinus | 0 | | 0.183 |
| Aplocheilidae | *Aplocheilus lineatus* | striped panchax | 0 | | 0.043 |
| Ariidae | *Arius* sp. | sea catfish | | 0 | 0.183 |
| Belonidae | *Xenentodon cancila* | Asian needlefish | 1 | | 0.557 |
| Blenniidae | *Omobranchus ferox* | fang-toothed blenny | 1 | | 0.780 |
| Callichthyidae | *Corydoras aeneus* ? | green corydoras | 1 | | 0.930 |
| Centrarchidae | *Lepomis cyanellus* | green sunfish | 1 | | 0.711 |
| Centrarchidae | *Lepomis macrochirus* | bluegill | 1 | | 0.939 |
| Centrarchidae | *Micropterus dolomieu* | smallmouth bass | 1 | 0 | 0.953 |
| Centrarchidae | *Micropterus salmoides* | largemouth bass | 1 | 0 | 0.990 |
| Centropomidae | *Lates calcarifer* | barramundi | | 0 | 0.060 |
| Channidae [a] | *Chana striata* | chevron snakehead | | 1 | --- |
| Channidae [a] | *Channa maculata* | blotched snakehead | 1 | 0 | 0.995 |
| Characidae | *Colossoma macropomum* ? | tambaquí | 0 | | 0.037 |
| Characidae | *Pygocentrus nattereri* | red piranha | 0 | | 0.165 |
| Cichlidae | *Amatitlania nigrofasciata* | convict cichlid | 1 | | 0.929 |
| Cichlidae | *Amphilophus citrinellus* | Midas cichlid | 1 | | 0.768 |
| Cichlidae | *Amphilophus labiatus* | red devil | 0 | | 0.840 |

Table 21. Status of nonindigenous freshwater fishes known to have been introduced into Hawaii and Guam since the late 1800s (status: 1 = established, defined as a self-sustaining, wild population; 0 = introduced, not known to be established; blank cells indicate species not known to have been introduced into that region). [Species not identified with certainty indicated by use of "cf.", "?", "sp ?" or "'complex." Thirteen such species of uncertain identification were included among the 80 species used in quantitative risk analysis. Shading indicates air-breathing species; fitted values for best model (#23) of establishment success in risk analysis (see text)]

| Family | Scientific name | Common name | Hawaii status | Guam status | Fitted value |
|---|---|---|---|---|---|
| Cichlidae | *Astronotus ocellatus* | oscar | 1 | 1 | 0.840 |
| Cichlidae | *Cichla ocellaris* ? | peacock cichlid | 1 | 1 | 0.954 |
| Cichlidae | *Cryptoheros spilurus* | blue-eyed cichlid | 1 | | 0.768 |
| Cichlidae | *Hemichromis elongatus* | banded jewelfish | 1 | | 0.768 |
| Cichlidae | *Hypsophrys nicaraguensis* | Nicaragua cichlid | 1 | | 0.768 |
| Cichlidae | *Melanochromis johanni* | bluegray mbuna | 1 | | 0.768 |
| Cichlidae | *Oreochromis macrochir* | longfin tilapia | 1 | | 0.929 |
| Cichlidae | *Oreochromis mossambicus* | Mozambique tilapia | 1 | 1 | 1.000 |
| Cichlidae | *Parachromis managuense* | jaguar guapote | 1 | | 0.954 |
| Cichlidae | *Pelvicachromis pulcher* | rainbow krib | 1 | | 0.768 |
| Cichlidae | *Pterophyllum* sp. | freshwater angelfish | 0 | | 0.768 |
| Cichlidae | *Sarotherodon melanotheron* | blackchin tilapia | 1 | | 0.768 |
| Cichlidae | *Thorichthys meeki* | firemouth cichlid | 1 | | 0.840 |
| Cichlidae | *Tilapia rendalli* | redbreast tilapia | 1 | | 0.992 |
| Cichlidae | *Tilapia zillii* | redbelly tilapia | 1 | 1 | 0.988 |
| Clariidae | *Clarias batrachus* | walking catfish | | 1 | 0.986 |
| Clariidae | *Clarias fuscus* | whitespotted clarias | 1 | | 0.948 |
| Clariidae | *Clarias macrocephalus* | bighead catfish | | 1 | 0.948 |
| Clupeidae | *Dorosoma petenense* | threadfin shad | 1 | | 0.815 |
| Cobitidae | *Misgurnus anguillicaudatus* | Oriental weatherfish | 1 | | 0.964 |
| Cyprinidae | *Carassius auratus* | goldfish | 1 | | 0.959 |
| Cyprinidae | *Ctenopharyngodon idella* | grass carp | 0 | 0 | 0.130 |
| Cyprinidae | *Cyprinus carpio* | common carp | 1 | 1 | 0.959 |
| Cyprinidae | *Hypophthalmichthys nobilis* | bighead carp | | 0 | 0.130 |
| Cyprinidae | *Puntius filamentosus* | blackspot barb | 1 | | 0.550 |
| Cyprinidae | *Puntius lateristriga* | spanner barb | | 0 | 0.550 |
| Cyprinidae | *Puntius semifasciolatus* | green barb | 1 | | 0.659 |
| Fundulidae | *Fundulus grandis* | Gulf killifish | 0 | | 0.043 |
| Gobiidae | *Mugilogobius cavifrons* | mangrove goby | 1 | | 0.780 |
| Ictaluridae | *Ameiurus nebulosus* | brown bullhead | 0 | | 0.123 |
| Ictaluridae | *Ictalurus punctatus* | channel catfish | 1 | 0 | 0.821 |
| Kuhlidae | *Kuhlia rupestris* | rock flagtail | 0 | | 0.183 |
| Loricariidae | *Ancistrus* cf. *temmincki* | suckermouth catfish | 1 | | 0.928 |
| Loricariidae | *Hypostomus* cf. *watwata* | suckermouth catfish | 1 | | 0.928 |

Table 21. Status of nonindigenous freshwater fishes known to have been introduced into Hawaii and Guam since the late 1800s (status: 1 = established, defined as a self-sustaining, wild population; 0 = introduced, not known to be established; blank cells indicate species not known to have been introduced into that region). [Species not identified with certainty indicated by use of "cf.", "?", "sp ?" or "'complex." Thirteen such species of uncertain identification were included among the 80 species used in quantitative risk analysis. Shading indicates air-breathing species; fitted values for best model (#23) of establishment success in risk analysis (see text)]

| Family | Scientific name | Common name | Hawaii status | Guam status | Fitted value |
|---|---|---|---|---|---|
| Loricariidae | *Peckoltia* sp. | peckoltia | 0 | | 0.086 |
| Loricariidae | *Pterygoplichthys multiradiatus* | Orinoco sailfin catfish | 1 | | 0.995 |
| Lutjanidae | *Lutjanus fulvus* | blacktail snapper | 1 | | 0.780 |
| Mochokidae | *Synodontis* sp. | squeaker catfish | 0 | | 0.043 |
| Moronidae | *Morone saxatilis* | striped bass | 0 | | 0.183 |
| Nothobranchiidae | *Nothobranchius guentheri* | redtail notho | 0 | | 0.043 |
| Osphronemidae | *Betta pugnax* | Penang betta | | 1 | 0.245 |
| Osphronemidae | *Osphronemus goramy* | giant gourami | 0 | | 0.890 |
| Osphronemidae | *Trichogaster leerii* | pearl gourami | 0 | | 0.339 |
| Osteoglossidae | *Osteoglossum bicirrhosum* ? | arawana | 0 | | 0.043 |
| Pangasiidae | *Pangasianodon hypophthalmus* | iridescent shark-catfish | | 0 | 0.465 |
| Plecoglossidae | *Plecoglossus altivelis* | ayu | 0 | | 0.183 |
| Poeciliidae | *Gambusia affinis* | eastern mosquitofish | 1 | 1 | 1.000 |
| Poeciliidae | *Limia vittata* | Cuban limia | 1 | | 0.390 |
| Poeciliidae | *Poecilia latipinna* | sailfin molly | 1 | 1 | 0.864 |
| Poeciliidae | *Poecilia mexicana/sphenops complex* | shortfin molly | 1 | | 0.910 |
| Poeciliidae | *Poecilia reticulata* | guppy Poeciliidae | 1 | 1 | 1.000 |
| | *Xiphophorus hellerii* | green swordtail | 1 | 1 | 0.998 |
| Poeciliidae | *Xiphophorus maculatus* | southern platyfish | 1 | 0 | 0.990 |
| Poeciliidae | *Xiphophorus variatus* | variable platyfish | 0 | | 0.503 |
| Salmonidae | *Oncorhynchus mykiss* | rainbow trout | 1 | | 0.630 |
| Salmonidae | *Oncorhynchus tshawytscha* | chinook salmon | 0 | | 0.146 |
| Salmonidae | *Salmo trutta* | brown trout | 0 | | 0.300 |
| Salmonidae | *Salvelinus fontinalis* | brook trout | 0 | | 0.146 |
| Synbranchidae | *Monopterus albus* ? | swamp eel | 1 | | 0.930 |

[a] Only one taxon (*Channa* spp.) was used in risk analysis models since this is a functional guild and we were unable to verify species identifications.

## Variables Used in Statistical Analysis

Many researchers have attempted to identify and describe the suite of characteristics important in determing the success and potential effects of invasive species (Moyle and Light 1996a, b; Kolar and Lodge 2001; 2002; Marchetti et al. 2004a, b; García-Berthou 2007; Hayes and Barry 2008; Bomford et al. 2009; Fujisaki et al. 2009; Bomford et al. 2010). Previous studies have suggested, for example, that many of the more successful fish invaders have the ability to reproduce rapidly, have a broad native distribution, and are habitat or diet generalists (Lodge 1993; Moyle and Light 1996a, b; Ricciardi and Rasmussen 1998). However, successful invasion also depends on the physical and biological characteristics of the receiving environment, given that some habitats appear to be more susceptible to invasion than others (Lodge 1993). Moreover, whether an introduction occurs and eventually results in establishment is heavily influenced by the types and availability of pathways and the corresponding number of individuals in the pathway that are then released into the region where they are not native; that is, propagule pressure (Lockwood et al. 2005; Wilson et al. 2009; Pyšek et al. 2010).

Based on previous studies of invasion success and our knowledge of many of the introduced fishes involved, a total of 15 different parameters (one dependent and 14 independent variables) were selected for analysis of the Hawaii and Guam nonindigenous fish dataset (Table 22). The dependent variable represented the establishment status of introduced taxa. Thirteen of the independent variables were as follows: family (taxonomic affinity); history (prior invasion success, based on the number of tropical islands or tropical island groups in which the taxon was introduced and became established; propagule pressure in the form of pathways of introduction; retail price; maximum body length; longevity; adult diet; trophic index; reproductive guild; spawning habitat; climate profile (based on the climate in a species' native range); salinity tolerance; and hypoxia tolerance). An additional independent parameter (variable 14) was developed that combined climate profile, salinity tolerance and hypoxia tolerance. These variables were scored based on (1) a survey of published literature; (2) other scientific and technical data, such as Fishbase® (Froese and Pauly 2011); (3) our own knowledge; or (4) closely related or similar species in cases where little information is available.

Certain types of biological variables are difficult to quantify precisely. Moreover, the ecology and life histories of many introduced fish species are not fully known; thus precluding assignment of exact values to some of the variables for many of the species in this analysis. Consequently, we relied primarily on categorical rather than continuous independent variables used in the predictive models. Each of the variables is summarized in Table 22 and described in greater detail in the following paragraphs.

Table 22. Variables pertaining to establishment success of nonindigenous fishes introduced to the Hawaiian Islands and Guam for use in risk analysis modeling. [Variables omitted from final model selections indicated by shading (see text)]

| Parameter | Description | States |
|---|---|---|
| Dependent variable | Status on Hawaii and/or Guam (established versus iintroduced but not established) | Two (0=not established; 1=established) |
| Independent variable | Taxonomic affinity | |
| | 1. Family | 34 different fish families |
| Independent variable | Distributional attributes and history of introductions | |
| | 2. History (prior invasion success, i.e., number of tropical islands/island groups where taxon was introduced and became established. | 0-43 |
| Independent variable | Propagule pressure | |
| | 3. Pathways | Twelve (1=raised in aquaculture facilities/ponds;2= in aquarium trade; 3=stocked as ornamental; 4=biological control; 5=stocked as food fish; 6=stocked as sport or game fish; 7=stocked as prey base; 8=used as bait; 9=present in live food markets; 10=ballast water; 11=contaminant with stocking of another species; 12=ceremonial release) |
| | 4. Retail price (per individual fish in aquarium, aquaculture trade, or live food market) | Four (1=over $50; 2=$21-$50; 3=$5-$20; 4=less than $5) |
| Independent variable | Life-history attributes | |
| | 5. Length (maximum adult size) | Four (1=small [<10 cm]; 2=medium [10-29 cm]; 3=large [30-100 cm]; 4=very large [>100 cm]) |
| | 6. Longevity | Three (1=short, less than 5 yr; 2=moderate, >5 to 10 yr; 3=long, >10 yr) |
| | 7. Diet (trophic guild; adult diet only) | Seven (1=detritivore/algivore; 2=herbivore; 3=planktivore; 4=omnivore; 5=invertivore; 6=invertivore/piscivore; 7=piscivore/top predator) |
| | 8. Trophic level index | 2.0-4.5; values derived from FishBase |

Table 22. Variables pertaining to establishment success of nonindigenous fishes introduced to the Hawaiian Islands and Guam for use in risk analysis modeling. [Variables omitted from final model selections indicated by shading (see text)]

| Parameter | | Description | States |
|---|---|---|---|
| | | 9. Reproductive guild (level of parental care, fecundity, and egg size) | Three (1=non-guarders, high fecundity, small egg; 2=guarder, medium fecundity and egg size; 3=bearer, low fecundity and large egg size [a]) |
| | | 10. Spawning habitat | Five (1=lotic; 2=lentic; 3=coastal/estuarine [b]; 4=lotic and lentic; 5=lotic, lentic and coastal/estuarine) |
| Independent variable | Physiological tolerance | | |
| | | 11. Climate profile (climate regions included in native geographic distribution) | Six (1=temperate; 2=subtropical; 3=tropical; 4=temperate/subtropical; 5=subtropical/tropical; 6=all) |
| | | 12. Salinity tolerance | Three (1=intolerant to salinity <1 ppm [stenohaline]; 2=moderately tolerant, >1 and <10 ppm; very tolerant, >10 ppm [euryhaline]) |
| | | 13. Hypoxia tolerance | Three (1=intolerant of low $O_2$; 2=moderately tolerant; 3=tolerant, air breathing) |
| | | 14. Environmental tolerance | 3-11 (a compilation of the scores from variables 11-13 above) |

[a] Includes live-bearing species (e.g., *Poecilia*), species that carry eggs externally (e.g., *Oryzias*, *Ancistrus*), and species that brood eggs internally in their orobranchial cavity (e.g., *Oreochromis*, *Melanochromis*).
[b] Includes species that spawn offshore or on reefs (e.g., *Anguilla marmorata*).

1. *Family* (*taxonomic affinity*). This variable was included to account for effects of phylogenetic relationships among species (Kolar and Lodge 2002; Alcaraz et al. 2005; Ruesink 2005; Bomford et al. 2009; Bomford et al. 2010). Fish family designations were based on Eschmeyer (2011).

2. *History* (*prior invasion success*). This variable is a measure of prior invasion success, defined in this study as the total number of tropical islands or island groups (excluding the Hawaiian Islands and Guam) where a species or taxon was introduced and became established. Prior invasion success is a parameter that has been identified as being positively correlated with the probability that a species will become established when introduced into a new area (Daehler and Strong 1993; Kolar and Lodge 2002; Marchetti et al. 2004a, b; Hayes and Barry 2008; Bomford et al. 2009; 2010). Data pertaining to the establishment of different fish taxa were based on review of published literature (important sources included Maciolek 1984; Welcomme 1988; Lever 1996; Eldredge 2000; Froese and Pauly 2000, 2011), consultation with subject-matter experts, and on original field work. Because information was limited to a taxon's history of establishment on tropical islands in the Pacific Ocean and other tropical regions of the world, this variable incorporates a form of climate matching (see Bomford et al. 2009; 2010).

3. *Pathways*. Principal pathways for introductions of freshwater fishes include aquaculture (Welcomme 1988; Fuller et al. 1999; De Silva et al. 2004), stocking of game fish (Fuller et al. 1999), releases of aquarium species (Courtenay and Stauffer 1990; Fuller et al. 1999; Rahel 2002; Padilla and Williams 2004), biocontrol of insects such as mosquitos, other fish species, or vegetation (Nelson and Eldredge 1991; Fuller et al. 1999), the live food industry (Fuller et al. 1999; Rixon et al. 2005), releases of bait fish (LoVullo and Stauffer 1993; Fuller et al. 1999), and ship ballast water (Ricciardi and MacIsaac 2000; Yamamoto and Tagawa 2000).

We distinguished 13 different pathway categories: (1) raised in aquaculture facilities or ponds; (2) used in the aquarium trade; (3) stocked for ornamental display; (4) used as biological control; (5) stocked as food fish; (6) stocked as sport or game fish; (7) stocked as forage for other fish; (8) stocked for conservation purposes to augment native populations or to establish new ones; (9) used as bait; (10) present in live food markets; (11) transported in ballast water; (12) contaminant unintentionally stocked with or instead of another species; and (13) used as part of religious or ethnic ceremonial release. It is worth noting that releases or stocking from research-related activities were not incorporated into the model but do occur.

The number and combinations of different pathways in which each taxon is known to have been introduced, either in Micronesia or any other part of the world, was determined based on the literature and other available information. Each pathway category was assigned a score of "1" and the number of pathways for each taxon was summed. Resulting values hypothetically could range anywhere from 1 to 13 and the summed value for each taxon was used for modeling. Frequency distributions by pathway for the data set of species included is depicted in Fig. 13.

We predicted that taxa with a higher pathway score would have a higher probability of establishment based on an *a priori* assumption that such taxa are more likely to have been introduced on multiple occasions or in large numbers over an extended time, reflecting high propagule pressure (Kolar and Lodge 2001; Lockwood et al. 2005; Ruesink 2005; Colautti et al. 2006; Duggan et al. 2006; Gertzen et al. 2008).

4. *Retail price*. This variable is the U.S. dollar value per individual fish in the aquarium fish trade, the aquaculture trade, or the live food market. We initially selected retail prices as a measure of propagule pressure, with the assumption that lower-priced animals would result in greater numbers of individuals in one or more pathways. However, it was not possible to obtain complete, accurate, or consistent retail pricing information for many of the fish species and the variable was later omitted from further consideration.

5. *Length (maximum adult size)*. This variable is a measure of the approximate maximum length that adult individuals achieve under good growth and survival conditions in the wild (Marchetti et al. 2004a). We elected to use only four different categories (mutually exclusive length size ranges), because (1) published and unpublished information on the size of fish in wild are often poorly documented, (2) some size data are probably associated with fish reared in captivity, and (3) methods of measurement vary (e.g., total length as opposed to standard length or fork length) and in some cases, are not reported. Information on maximum body length was obtained primarily from the online database FishBase® (Froese and Pauly 2011), Page and Burr (1991), and Fuller et al. (1999). Frequency distributions of the number of taxa in each size class are presented in Fig. 14.

According to Crawley (1986), species with a higher intrinsic rate of increase, *r*, are more likely to become established. Ruesink (2005) suggested that large species of fish may have a relatively low probability of establishment success based on the *r*–K continuum. However, Crawley (1986) also suggested the effect of body size on establishment success might depend on the type of competition faced by an introduced species. Additionally, species held as pets that attain a large size may be more likely to be released by owners once the animals outgrow their aquaria (Gertzen et al. 2008), thereby resulting in higher propagule pressure and likelihood of establishment in the wild. Maximum length was not included in the best model of establishment success reported by Kolar and Lodge (2001) or by Marchetti et al. (2004b). However, maximum length was included in the best model of establishment success reported by Marchetti et al. (2004a), although slopes for maximum length were not reported in that study.

6. *Longevity*. Initially we categorically scored species for longevity. This variable was eventually omitted for three reasons: (1) maximum lifespans reported in the literature are highly variable and some values are suspect (e.g., for many species maximum age is derived from information on live fish maintained in captivity although it is widely known that captive individuals often live much longer than those in the wild); (2) for many species, this information is simply unavailable; and (3) general maximum adult length (variable 5) and longevity are assumed to be closely correlated. Frequency distributions of number of taxa in each lifespan category are presented in Fig. 14.

7. *Diet* (*trophic guild*). This variable was a descriptor of the diets of adult fish. We recognized seven different diet categories or trophic guilds, ranging from detritivore/algivore (category 1) to top carnivore (category 7). The classification was based heavily on qualitative and quantitative information available in FishBase® (Froese and Pauly 2011), Goldstein and Simon (1999), and personal knowledge of the authors. For species for which there was little or nothing published, classification was based on information published for closely related or similar species. Frequency distributions showing the number of taxa in each trophic category are presented in Fig. 15.

Based on an analysis of terrestrial animals (mainly insects) in Europe, Crawley (1986) stated that herbivores are more likely to become established than carnivores or detritivores because herbivores experience less competition. In assessing fish invasions in California, Moyle and Light (1996a) also suggested that trophic status is an important predictor of establishment success, but they argued that piscivores and detritivores/omnivores appeared to have greater establishment success, with the caveat that such an outcome was most likely in aquatic habitats where there were low levels of human disturbance. Ruesink (2005) found that establishment success was higher for omnivorous fishes, which is consistent with the hypothesis that generalists are particularly well suited to invading new areas (Blackburn et al. 2009). However, Moyle and Marchetti (2006) reported finding no evidence of such relationships. Kolar and Lodge (2002) created a complex index of diet by combining diet breadth and foraging habitat, and found their resulting index to be correlated with establishment success.

8. *Trophic level index*. Trophic levels among fishes generally range from 2 for herbivores and detritivores to 4.5 or higher for certain top predators (Froese and Pauly 2000, 2011). We initially considered using a continuous trophic variable based on a quantitative index from FishBase® that combines diet composition with the trophic level of food items consumed (see *http://www.fishbase.org/manual/English/fishbasethe_ecology_table.htm*). We subsequently determined that the Fishbase® trophic level index values trended positively with our categorical classification (Fig. 16). Based on that comparison, we decided to omit the trophic level index from our models and, for fish trophic information, only the diet or trophic guild categorical variable (variable 7) was used in model analyses and to estimate separate slopes for each taxon.

9. _Reproductive guild (level of parental care, fecundity, and egg size)_. We recognized three general reproductive guilds for introduced fish, with each of the categories representing important life-history characteristics that tend to be negatively correlated; for example, the level of parental care compared to the number and size of eggs. Reproductive guild or parental care was examined as a factor of invasive success in fishes by Kolar and Lodge (2002) and Marchetti et al. (2004a, b). Annual fecundity and egg size were also included in the variable pool used by Kolar and Lodge (2002). We considered these variables to be closely related, and combined them into a single categorical variable based in part on Goldstein and Simon (1999) and on personal knowledge. Ruesink (2005) suggested that species with high fecundity may have higher establishment success. Moyle and Marchetti (2006) noted that species with intermediate or mixed life history characteristics are most likely to be successful invaders. We predicted that species with an intermediate score of our categorical variable would have highest establishment success. Frequency distributions of number of taxa in each reproductive guild are presented in Fig. 15.

10. _Spawning habitat_. We recognized five categories to distinguish the range of habitats used by island fishes for spawning. The ecological variable provides information on habitat type and distinguishes between species requiring a certain type of environment (e.g., lentic versus lotic) versus those species that are more flexible in their spawning requirements (e.g., lentic and lotic). Among the different types of habitats used by fish, it was assumed that spawning habitat would likely be the most important in determining establishment success. In the absence of appropriate spawning habitat, an introduced species might briefly survive and grow, but ultimately would fail to reproduce or persist. Marchetti and Moyle (2001) found that flow regime affected population persistence of nonindigenous fishes. Frequency distributions based on number of taxa in each spawning habitat category are presented in Fig. 17.

11. _Climate profile_. This variable is an indication of the types and numbers of different climate regions included in the species' native geographic range. We recognized six categories that provided information on the type of climate and also distinguished between species whose native range encompassed one or a few climate regions from those whose native range was much more widespread in terms of latitude and climate. Assignment of the different fish species to particular categories was based on information provided in the scientific literature, other sources (Froese and Pauly 2011), and our own observations and research. Climate profiles have been used in various species distribution models, including some (e.g., climate matching) intended for predicting the potential range of a nonindigenous species based on similarity to climates found in the species' native range (Peterson 2003; Franklin 2009). Frequency distributions of number of taxa in each size climate category are presented in Fig. 17.

The presence, absence, and relative abundance of a species in a climatic region are affected by their tolerance of, or preference for, ambient temperature. A general assumption is that climate is closely correlated with particular temperature ranges, and therefore, approximates a species' relative temperature tolerance. Those species that have broad thermal tolerance are generally considered to have a greater probability of establishment success (Kolar and Lodge 2002; Moyle and Marchetti 2006; Blackburn et al. 2009). Rather than attempt to estimate the range of temperatures suitable for survival and reproduction based on limited or nonexistent data for many species, we used a categorical classification of climate in the species' native range as a surrogate (i.e., distribution in temperate, subtropical, and/or tropical regions). This represents a qualitative form of climate matching used in some studies of establishment success (Bomford et al. 2009; Fujisaki et al. 2009; Bomford et al. 2010). We predicted that tropical and subtropical species were most likely to establish successfully in Guam and Hawaii.

12. *Salinity tolerance*. As with temperature, a wide zone of salinity tolerance may increase probability of establishment success (Kolar and Lodge 2002; Moyle and Marchetti 2006; Blackburn et al. 2009). We used a categorical variable with three levels and predicted *a priori* that species tolerant to high salinities (euryhaline) would have highest establishment success. The classification scheme and assignment of the different fish species to particular categories was based on the scientific literature, other sources (e.g., FishBase®; Froese and Pauly 2011), personal knowledge, or inference from what is known about similar species. Species identified as intolerant to salinity (stenohaline) were predicted to have lowest establishment success. Frequency distributions of number of taxa in each salinity tolerance category are presented in Fig. 18.

13. *Hypoxia tolerance*. Hypoxia tolerance refers to the ability of a species to inhabit water with low dissolved oxygen levels. As with temperature and salinity, we created a categorical variable having three levels. The classification scheme and assignment of the different fish species to particular categories was based on the scientific literature, other sources (e.g., FishBase®; Froese and Pauly 2011), personal knowledge, or inference from what is known about similar species. Species that are very tolerant of low dissolved oxygen levels (i.e., air breathers and those capable of aquatic surface respiration) were predicted *a priori* to have the highest establishment success. Frequency distributions of the number of taxa in each hypoxia tolerance category are presented in Fig. 18.

14. *Environmental tolerance (climate profile + salinity tolerance + hypoxia tolerance)*. As an alternative to using three independent environmental tolerance variables, we combined climate profile (an approximation of temperature tolerance), salinity tolerance, and hypoxia tolerance. Their composite scores produced a new single variable that we referred to as "environmental tolerance." For example, a temperate species that cannot tolerate salinity or low dissolved oxygen levels received an environmental tolerance score of 3 (equaling 1+1+1 for each factor) whereas a tropical species tolerant of high salinities and low dissolved oxygen levels received a physiological tolerance score of 9 (equaling 3+3+3). This variable was treated as an ordinal number to reduce the number of parameters in the most general model and to facilitate model convergence.

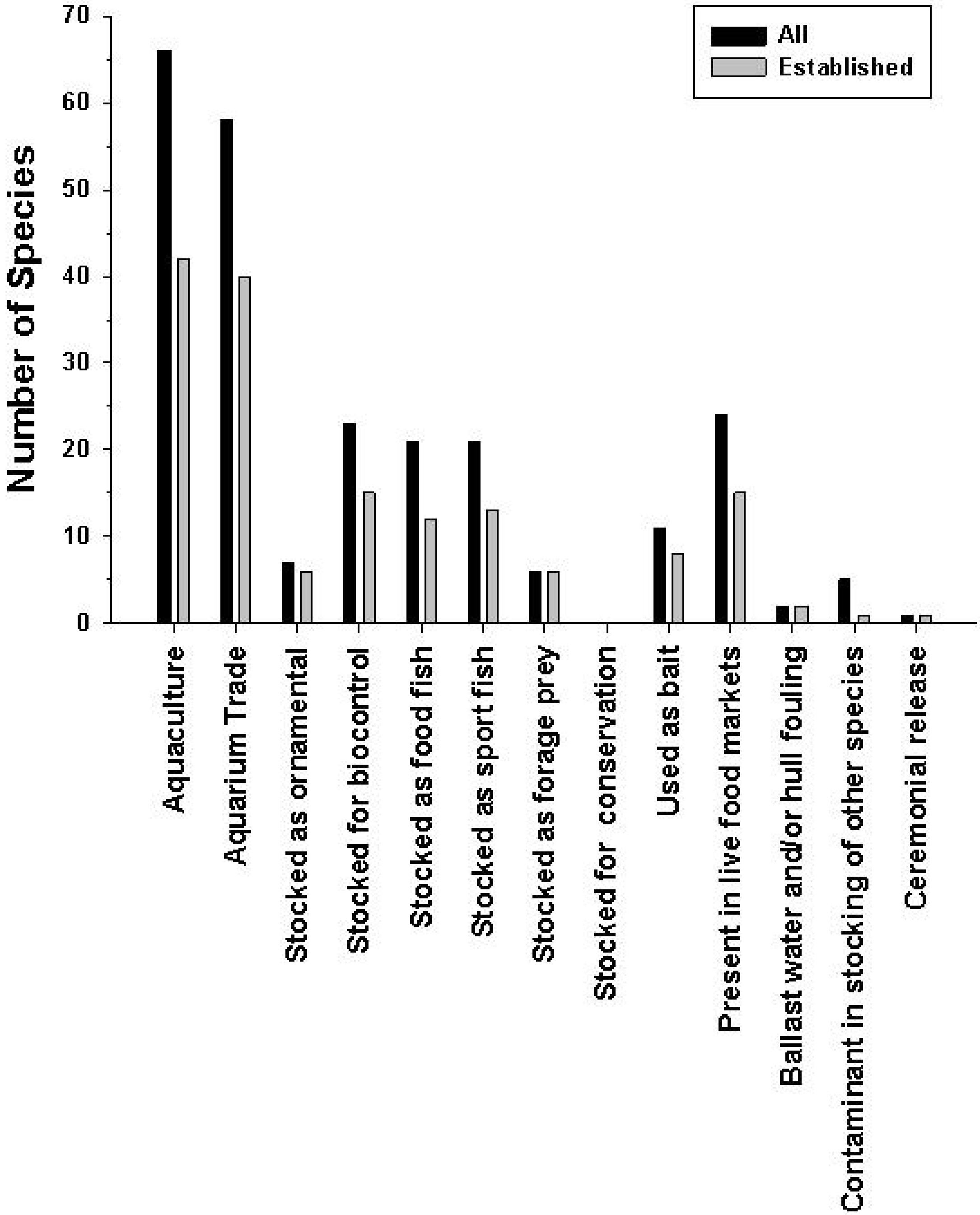


Figure 13. Number of nonindigenous freshwater fish species or taxa by known or presumed pathway of introduction in Hawaii and Guam. All = failed plus successful introductions (i.e., includes both established and non-established, nonindigenous fish species or taxa); established = only those known to have reproducing populations (graph based on data matrix used in model analyses and sources of data indicated in text).

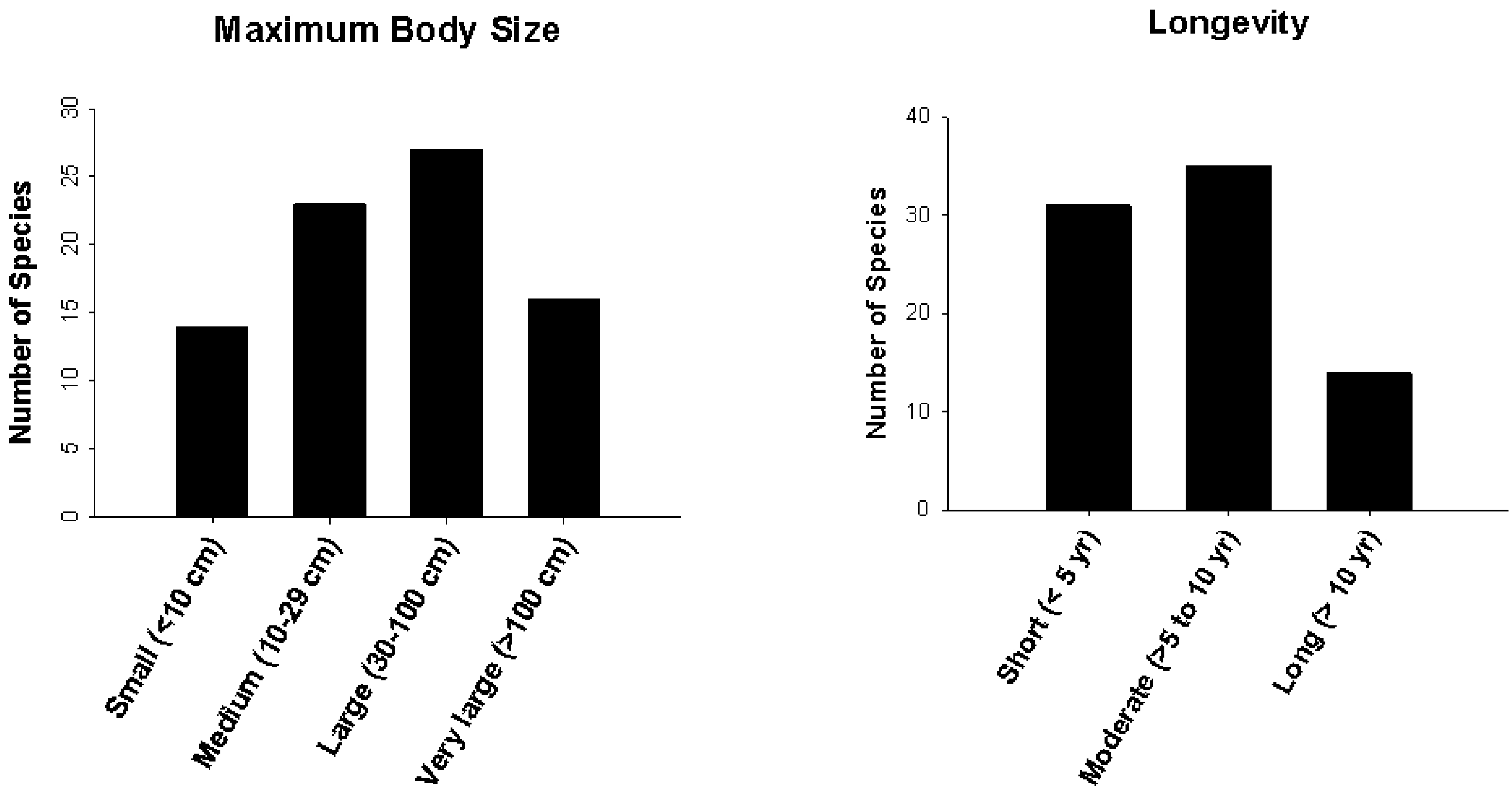


Figure 14. Frequency distribution by body size category and longevity of fishes scored for risk analysis (longevity was omitted from modeling; see text).

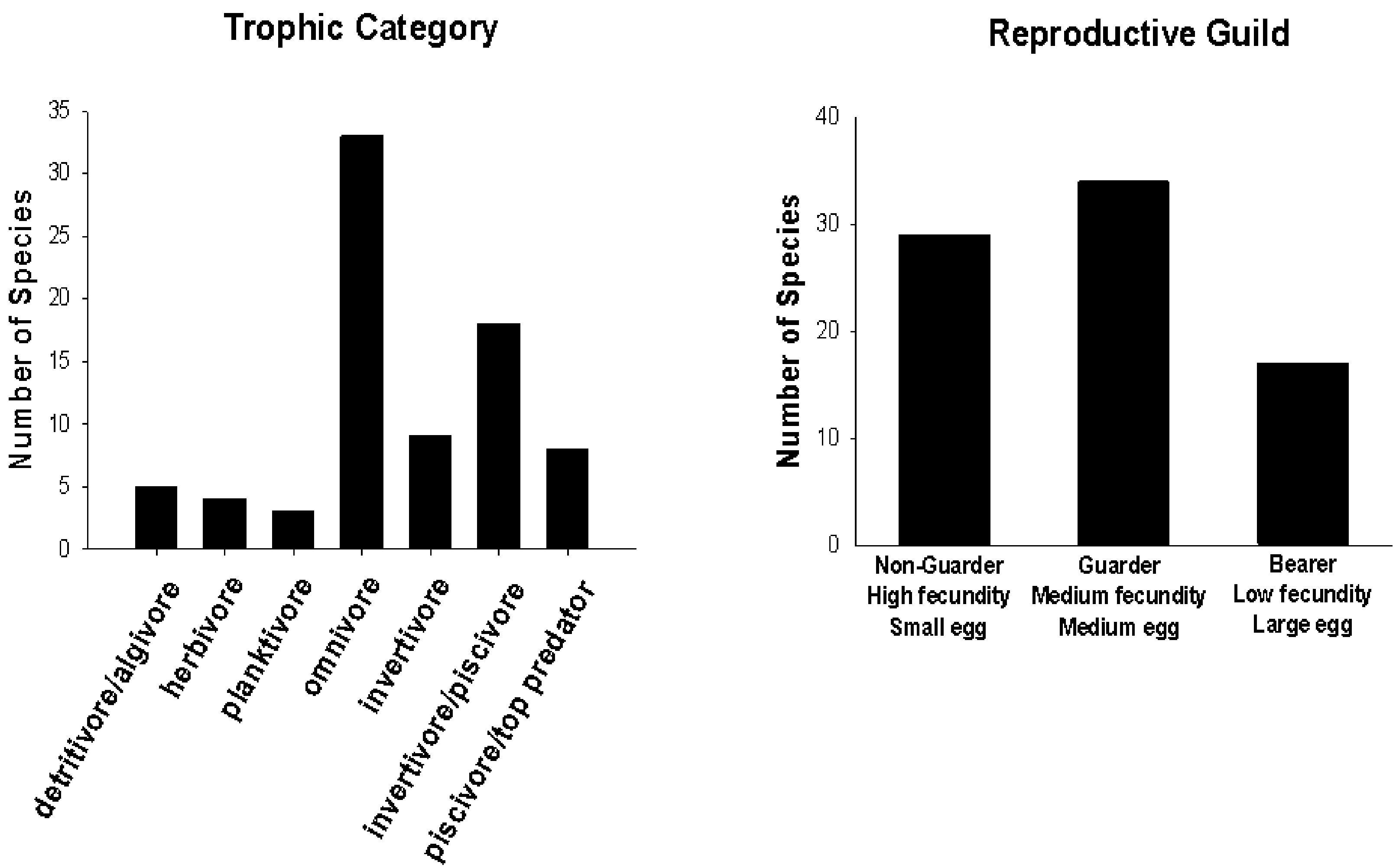


Figure 15. Frequency distribution by trophic category and reproductive guild of fishes scored for risk analysis.

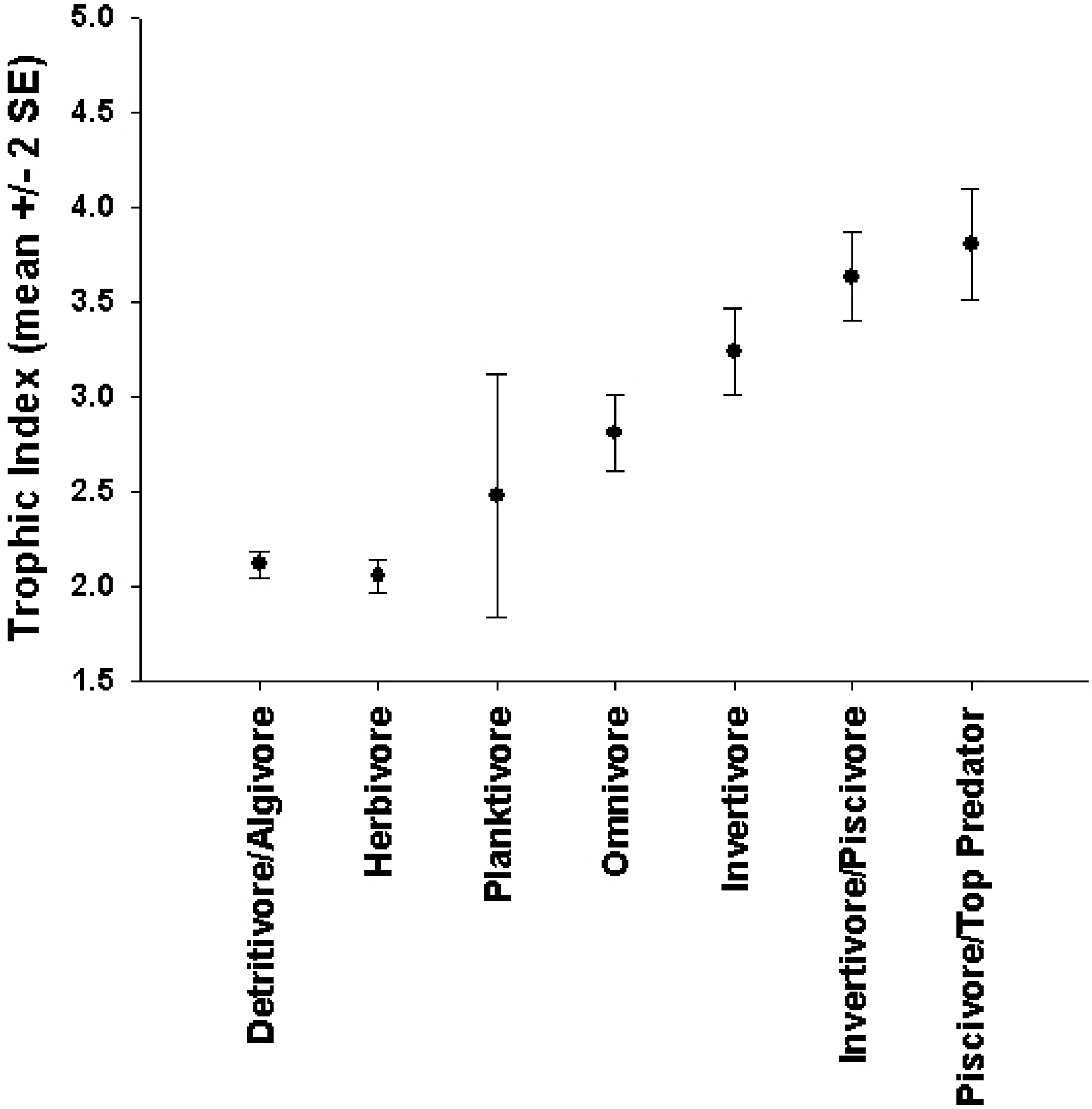


Figure 16. Relationship between trophic categories used in risk analysis versus trophic level index values appearing in species accounts of FishBase® (Froese and Pauly 2011). Mean +/-2Standard Error (SE) of species used in risk analysis matrix (for a few taxa not identified to species, mean trophic index from FishBase® was calculated as mean from congenerics or family for available values).

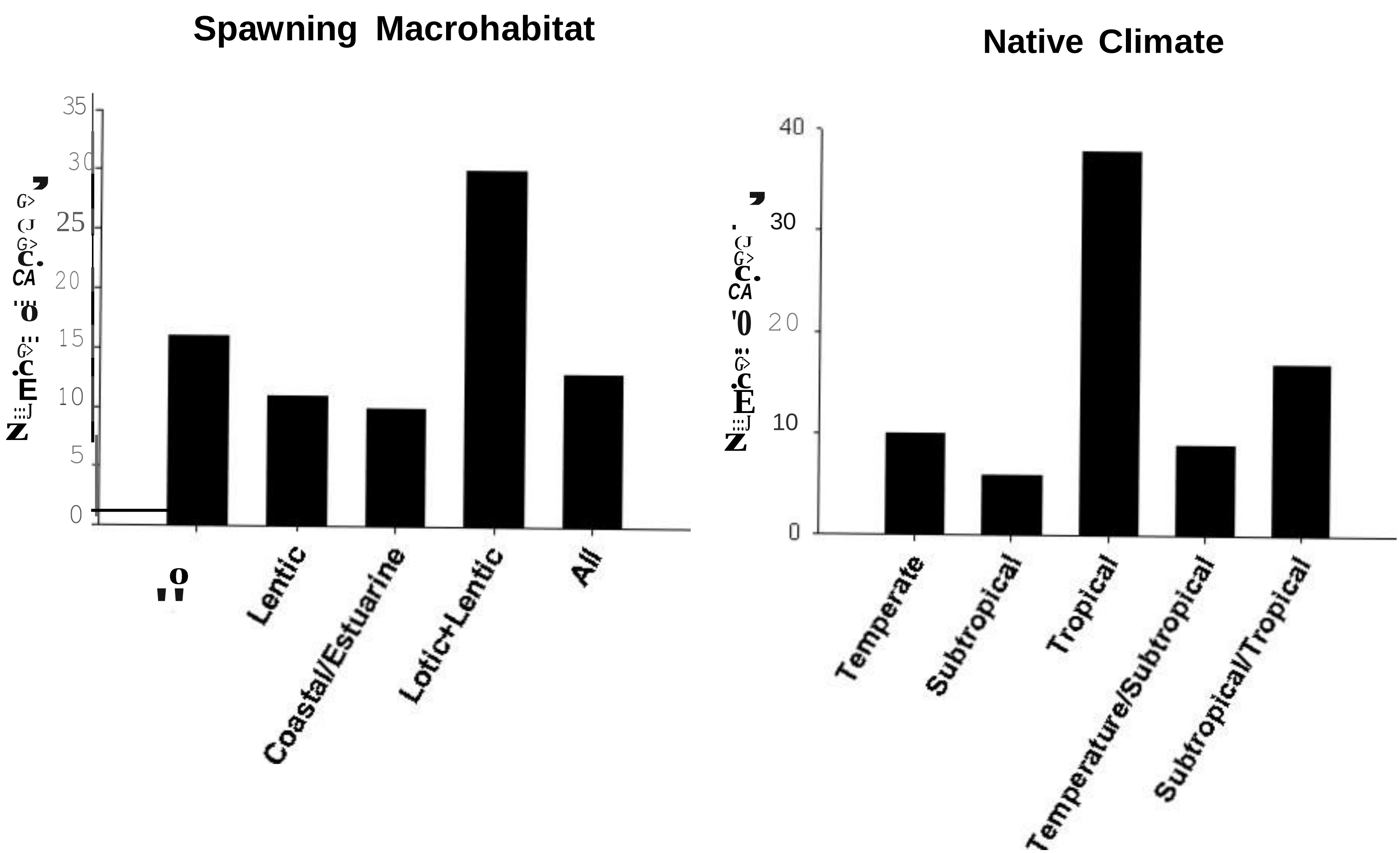


Figure 17. Frequency distribution by spawning habitat and thermal requirement (climate in native range) of fishes scored for risk analysis.

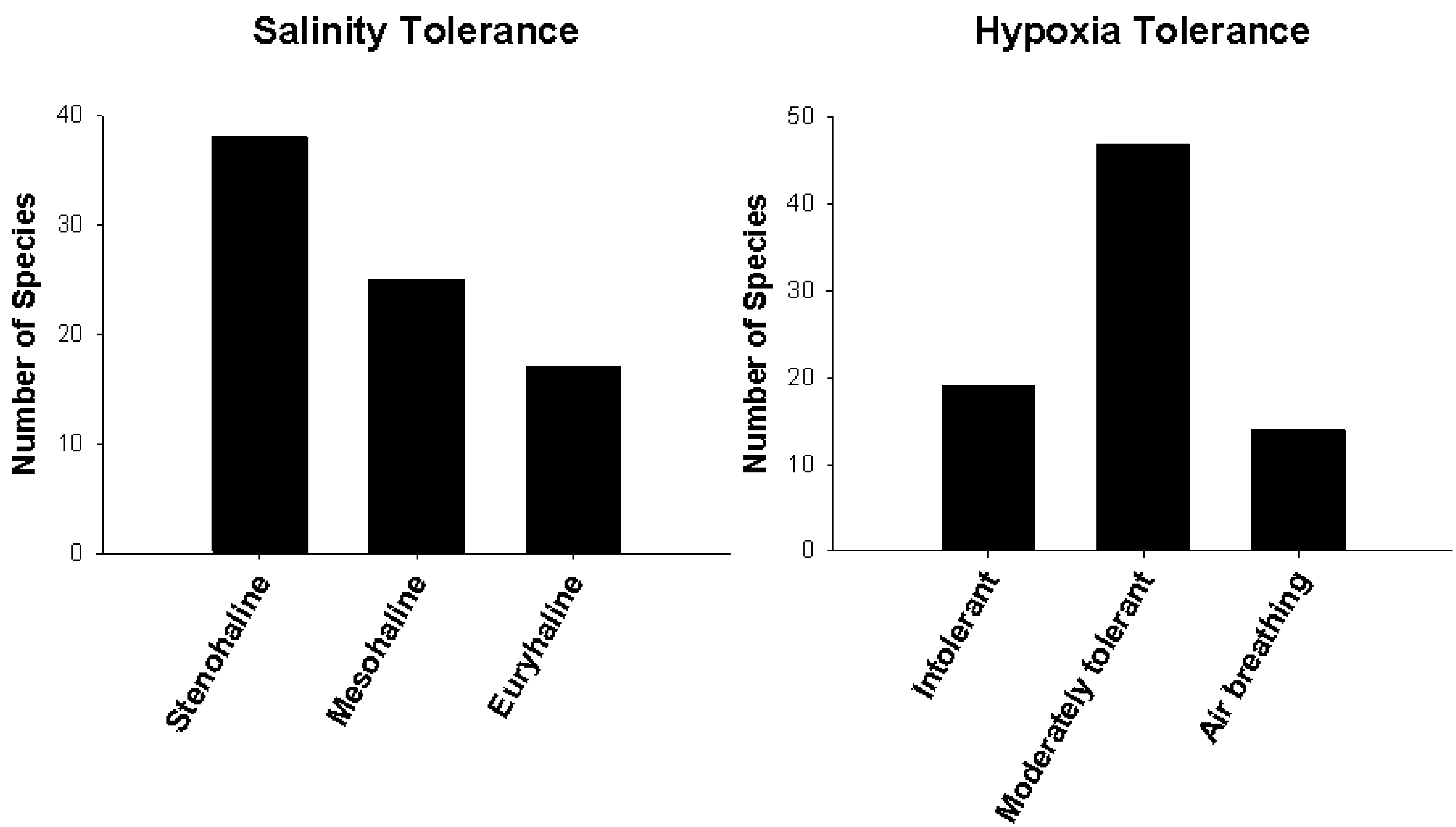


Figure 18. Frequency distribution by physiological tolerance categories of fishes scored for risk analysis.

## Model Set

Establishment success was a binary response variable defined as equaling 1 for nonindigenous fish species with a self-sustaining reproducing population in the wild in Hawaii or Guam, and equaling 0 for nonindigenous fish species introduced but not known to be established in the wild in those two areas. We used logistic regression for our analysis because of the binary nature of our response variable (Agresti 2002). Our use of logistic regression followed methods of several previous authors who have predicted establishment success of nonindigenous species (Marchetti et al. 2004a, b; Ruesink 2005; Ribeiro et al. 2008; Bomford et al. 2009; Fujisaki et al. 2009; Bomford et al. 2010). The data matrix used in our analysis of establishment success is provided in Appendix 2.

We created a set of 21 competing *a priori* logistic regression models each representing a different hypothesis regarding establishment success (Table 23). This model set included our most general model, which contained eight independent variables. We included the composite variable ("environmental tolerance") created by combining climate profile, salinity tolerance, and hypoxia tolerance, to achieve convergence of the most general model. The remaining 20 models in the set each included a unique subset of the independent variables in the most general model. Most of the competing models were created by reviewing the literature. Not all models from the literature could be reproduced exactly using our variable set. In such cases, we approximated published models as closely as possible with the variables in our set. A few additional competing models were added based on our hypotheses of possible combinations of variables that might have predictive power.

Each of the 21 *a priori* models in our model set were ranked using Akaike's Information Criterion, $AIC_c$, adjusted for small sample size (Burnham and Anderson 2002). The best model has the lowest $AIC_c$. We calculated Akaike weights, $w_i$, to evaluate support for each model and for individual variables. These Akaike weights sum to 1.0, and indicate relative support for a given model. Climate, salinity and hypoxia were added to the best model in an exploratory *post-hoc* fashion by creating seven additional models to represent every possible combination of these three physiological variables. Summary output for all of the models and associated R code is available from the authors upon request.

Table 23. Set of competing models of establishment success for nonindigenous fishes introduced into Hawaii and Guam since the late 1800s and the hypotheses that each model represents. [The first 21 models were created *a priori*. Models 22-28 were *a posteriori* variations of the *a priori* model with the most support. Model 29 was an *a posteriori* version of the best model among models 1 – 28 in which the number of hypoxia tolerance scores were reduced from 3 to 2]

| Model No. | Model name | Hypothesis | Reference |
|---|---|---|---|
| 1 | Family + history + pathways + length + diet + reproductive guild + spawning habitat + environmental tolerance | Our most general model | Present study |
| 2 | Family + history + pathways + length + diet + reproductive guild + environmental tolerance | Best model of Marchetti et al. (2004a) | Marchetti et al. (2004a) |
| 3 | Family + pathways + length + diet + reproductive guild + environmental tolerance | Invasive species characteristics | Kolar and Lodge (2001) |
| 4 | Family + history + pathways + length + reproductive guild + environmental tolerance | Expert opinion model | Marchetti et al. (2004a) |
| 5 | Family + history + pathways + diet + spawning habitat + environmental tolerance | Human interest and habitat generalist | Present study |
| 6 | Family + history + pathways + reproductive guild + environmental tolerance | Best model in a different study | Marchetti et al. (2004b) |
| 7 | Family + length + diet + reproductive guild + spawning habitat | Life history | Present study |
| 8 | Family + pathways + diet + environmental tolerance | Invasive species characteristics | Moyle and Light (1996a, b) |
| 9 | Family + diet + reproductive guild + environmental tolerance | Kolar and Lodge (2002) best model 1 | Kolar and Lodge (2002) |
| 10 | Family + history + reproductive guild + environmental tolerance | Kolar and Lodge (2002) best model 2 | Kolar and Lodge (2002) |
| 11 | Family + pathways + reproductive guild + spawning habitat + environmental tolerance | Propagule pressure, population growth and habitat | Williamson and Fitter (1996) |
| 12 | Family + diet + spawning habitat + environmental tolerance | Habitat generalist | Present study |
| 13 | Family + diet + environmental tolerance | Ecological characteristics or novel environments | Marchetti et al. (2004a) |

Table 23. Set of competing models of establishment success for nonindigenous fishes introduced into Hawaii and Guam since the late 1800s and the hypotheses that each model represents. [The first 21 models were created *a priori*. Models 22-28 were *a posteriori* variations of the *a priori* model with the most support. Model 29 was an *a posteriori* version of the best model among models 1 – 28 in which the number of hypoxia tolerance scores were reduced from 3 to 2]

| Model No. | Model name | Hypothesis | Reference |
|---|---|---|---|
| 14 | Family + length + reproductive guild | Life history or high population growth | Marchetti et al. (2004a) |
| 15 | Family + history + pathways | Human interest | Marchetti et al. (2004a) |
| 16 | Family + pathways + diet | Best model in a different study | Ruesink (2005) |
| 17 | Family + history + spawning habitat | Prior establishment success and spawning habitat | Present study |
| 18 | Family + history + length | Best model in a different study | Ribeiro et al. (2008) |
| 19 | Family + history | Taxonomic affinity + Prior establishment success | Bomford et al. (2010) |
| 20 | Family + pathways | Propagule pressure | Blackburn et al. (2009) |
| 21 | Family | Taxonomic effect only | Present study |
| 22 | Family + history + climate profile | Best *a priori* model + climate profile | Bomford et al. (2010) |
| 23 | Family + history + hypoxia tolerance | Best *a priori* model + hypoxia tolerance | Present study |
| 24 | Family + history + salinity tolerance | Best *a priori* model + salinity tolerance | Present study |
| 25 | Family + history + climate profile + hypoxia tolerance | Best *a priori* model + climate profile + hypoxia tolerance | Present study |
| 26 | Family + history + climate profile + salinity tolerance | Best *a priori* model + climate profile + salinity tolerance | Present study |
| 27 | Family + history + hypoxia tolerance+ salinity tolerance | Best *a priori* model + hypoxia tolerance + salinity tolerance | Present study |
| 28 | Family + history + climate profile + hypoxia tolerance + salinity tolerance | Best *a priori* model + climate profile + hypoxia tolerance + salinity tolerance | Present study |
| 29 | Family + history + hypoxia tolerance | Best *a priori* model + hypoxia with number of hypoxia scores reduced from 3 to 2 (hypoxia scores of 1 and 2 lumped vs. 3) | Present study |

## Model of Observations

To specify differences in establishment among species, we formulated the probability of establishment (on the logit scale) as a linear combination of Random and fixed covariates:

$$\mathrm{logit}(p_{\mathrm{it}}) = \boldsymbol{\beta'}\, x_{sp} + \beta_3 \mathrm{var2}_{sp} + \beta_4 \mathrm{var3}_{sp} + \beta_5 \mathrm{var5}_{sp} + \ldots \ldots + \beta_{20} \mathrm{var8}_{sp}$$

where $\boldsymbol{\beta'}$ is a Random family effect and $x_{sp}$ is the family for a given species, *sp*, (Bomford et al. 2009). Two parameters are estimated for this Random effect: a mean and a standard deviation. All other variables in the model are species-level fixed effects. The variable var2 represents number of tropical islands or island groups for a given species (*sp*), $\beta_3$ is the slope for that variable, var3 represents human-use score, $\beta_4$ is the slope for that variable, var5 is a binary, dummy variable used to codify one level of our maximum length variable, $\beta_5$ is the slope for that variable, var8 represents the composite environmental tolerance, and $\beta_{20}$ is the slope for that variable. Model parameters were estimated using the "lmer" function for linear mixed models (Gelman and Hill 2007) in Program R (R Development Core Team 2004). Each of the 21 *a priori* competing models included a Random family effect. When no Random effect is supported by the data the lmer function estimates a constant intercept with a variance of zero, essentially removing the Random family effect from the model.

After identification of the best model, we assessed fit of that model by estimating its error rate (Gelman and Hill 2007). The error rate is the proportion of observations in the data set for which the fitted value > 0.5 and species status in the study area = 0, or fitted value < 0.5 and status = 1. We compared the error rate of the best model to the error rate of the null model. The null model is simply the proportion of observations in the data set for which species status is one. The error rate of the null model is 1; that is, the proportion of observations in the data set with a species status of one. Ideally, the error rate of the best model is low and substantially lower than the error rate of the null model.

We also assessed fit of the most general model by creating 1,000 simulated data sets based on that model (Gelman and Hill 2007). We used the proportion of observations in the data set with a species status of 0 as our test statistic and compared the value of that test statistic to the same proportion for each of the 1,000 simulated data sets. A two-sided *p*-value was used to estimate whether the actual test statistic differed significantly from values obtained by means of simulation.

## Results

Table 24 includes summary information on the numbers of introduced and established nonindigenous fishes on Guam and the Hawaiian Islands, as well as selected information on the variable "history," a measure of their invasion success (establishment) on other tropical islands. The 80 nonindigenous fish taxa included in this analysis include only those species and taxa known to have been introduced into inland waters of Guam, Hawaii, or both, regardless of whether their introduction resulted in establishment (i.e., 49 taxa established and 31 not established).

Many of the nonindigenous fish taxa introduced to Guam or Hawaii (42 of the 80 taxa; 52.5%) are considered established on other tropical islands or island groups. However, most (72 taxa, 90%) of the 80 Guam/Hawaii nonindigenous taxa are either not established on other tropical islands or are established on relatively few islands (eight or fewer) (Fig. 19). A few species are widely established among different tropical islands or island groups. The most extreme examples include (1) Mozambique tilapia, *Oreochromis mossambicus*, recorded as established in as many as 43 other tropical islands or island groups; and (2) three different members of the family Poeciliidae: the guppy *Poecilia reticulata*, established in 30 other tropical islands or island groups; the mosquitofish *Gambusia affinis/holbrooki*, established in 23 other tropical islands or island groups; and the swordtail *Xiphophorus hellerii*, established in 15 other tropical islands or island groups. All four of these taxa are also established in Guam and Hawaii.

Of the 80 nonindigenous fish taxa, 26 are established both in Hawaii or Guam and on at least one other tropical island. Among those 38 species not established on any other tropical islands, 20 (51%) are documented as established in Hawaii or Guam. Twenty-two of the 23 species (96%) introduced into Hawaii or Guam and established on at least three other islands or island groups also are established in Hawaii or Guam. *Osphronemus goramy* was established in seven other tropical islands or island groups, but did not become established after being introduced into Hawaii.

The 80 nonindigenous fish taxa (including grouped forms) in our analysis represented 30 families (Table 21). Family Cichlidae was represented by the most species (18), followed by Poeciliidae (8), Cyprinidae (7), Centrarchidae (4), Loricariidae (4), and Salmonidae (4). Of the 30 total families, 22 (73%) were represented by only one species. Inclusion of families with only one species does not present a problem when using a Random family effect (Gelman and Hill 2007). Overall, 50 of 81 (62%) introduced species were considered established. For the purpose of model simulation, the two species of *Channa* were treated as one taxon (i.e., *Channa maculata* on Hawaii, *C. striata* on Guam, neither identification of which was verified). Because of continued taxonomic confusion and problems in positive identification, all members of certain other genera (e.g., *Hypostomus*) were also treated as one taxon even though records could actually have been based on more than one member of that group.

The number of species introduced through means of each of the 12 pathways described earlier (and the percentage that became established) was as follows: raised in aquaculture facilities/ponds, 64 (63%); used in the aquarium trade, 58 (68%); stocked as ornamental, 7 (86%); biological control, 22 (64%); stocked or transported as food fish, 20 (55%); stocked as sport or game fish, 20 (60%); stocked as prey base (forage), 6 (20%); used as bait, 11 (73%); present in live food markets, 23 (61%); transported in ballast water, 2 (100%); contaminant with other stocking, 5 (20%); and used for ceremonial release, 1 (100%) (Fig. 13). We did not score any species as having been introduced for conservation purposes; although *Kuhlia rupestris* has been stocked in Australia to restore populations (Hutchison et al. 2002); we did not score it as such because its introduction to Hawaii would not have been for this reason.

The best model (#23) of establishment probability included a Random family effect with a nonzero standard deviation ($SD$ = 2.61), an effect of history (i.e., prior invasion success on tropical islands or island groups), and an effect of hypoxia tolerance (Table 25). This model had substantial support (Akaike weight = 0.59, evidence ratio = $w_{25}/w_{27}$ = 6.4). No other model had an Akaike weight > 0.09. The second, third, and fourth best models were the only other models with an Akaike weight > 0.05, and these three models were minor variations of our best model.

Effect of history variable in our best model had a positive slope, as expected ($\hat{\beta}_{\text{history}}$ = 0.45, $S\hat{E}$ = 0.19), suggesting establishment probability in Hawaii and Guam was higher for species established on a large number of islands or islands groups other than Hawaii and Guam. According to our best model, air-breathing fishes (hypoxia score = 3) were most likely to become established ($\hat{\beta}_{\text{hypoxia 3}}$ = 2.36, $S\hat{E}$ = 1.71). Fourteen air-breathing species were included in our study, and 11 of these species (79%) are established (Table 21).

Point estimates for the Random family effect in our best model ranged from -3.48 to 3.76 (Table 26). Of the nine families represented by ≥ 2 species, Cichlidae (3.76), Centrarchidae (2.54), and Poeciliidae (2.11) had the highest point estimates, representing high establishment probability. The families Osphronemidae (-3.48), Salmonidae (-1.76), and Anguillidae (-0.88) had the lowest point estimates, indicating low establishment probability.

We plotted probability of establishment based on our best model using a fixed intercept that incorporated the history variable as the x-axis (Fig. 20). Equations for each of the lines in Fig. 20 are as follows:

<u>Species with hypoxia tolerance score of 1:</u>

-0.2399136 + 0.4597635*(number of islands)

<u>Species with hypoxia tolerance score of 2:</u>

-0.2399136 + 0.4597635*(number of islands) + (-2.562265)

<u>Species with hypoxia tolerance score of 3:</u>

-0.2399136 + 0.4597635*(number of islands) + (2.355279)

Species that are intolerant of low dissolved-oxygen levels (hypoxia tolerance score of 1) had a 0.44 probability of becoming established if they were not established on any other tropical islands or island groups. The probability of establishment increased to 0.66 if these species were established on two other tropical islands or island groups. Species with a hypoxia tolerance score of 2 had only a 0.06 probability of becoming established if they were not established on any other tropical islands or island groups. Their probability of becoming established increased to 0.38 if they were established on 5 other tropical islands or island groups, and increased to 0.49 if they were established on 6 other tropical islands or island groups. Air-breathing species (hypoxia tolerance score of 3) had a 0.89 probability of becoming established if they were not established on any other tropical islands or island groups. Probability of establishment increased to 1.00 for all species as the number of tropical islands or island groups on which they were established elsewhere increased. We created one more *a posteriori* variant of our best model in which species with a hypoxia tolerance score of 1 or 2 were grouped and given a new hypoxia tolerance score of 1, while the hypoxia tolerance score for air-breathing species was changed from 3 to 2. However, that new model had only half as much support as the best model reported in Tables 25-26.

We also plotted estimated probability of establishment for individual fish families represented by more than 3 species based on our best model (Fig. 21). Species in the family Cichlidae had a 0.77 probability of establishment when not established elsewhere. All species in that family had a hypoxia tolerance score of 2. Species in the family Salmonidae had only a 0.15 probability of establishment when not established elsewhere. All salmonids had a hypoxia tolerance score of 1. Species in the family Poeciliidae had a 0.40 probability of establishment when not established elsewhere. Snakeheads (Family Channidae) had an estimated establishment probability of 0.90 when not established elsewhere; as previously noted, the two species of snakeheads recorded for Hawaii and Guam were treated as a single taxon in our model. Species of Channidae are established on at least seven other tropical islands or island groups, and the fitted value of establishment probability for that taxon was 1.0.

Using our best-fit model we scored parameters for a set of nine taxa representing eight families not known to be currently established in Hawaii or Guam to predict probability of future establishment. These taxa were selected based on their known or presumed likelihood of presence in pathways under consideration, primarily popularity or novelty in the aquarium trade and species used for aquaculture, food, bait, or as biocontrol agents. The establishment probability for four of these taxa was greater than 70% and two were greater than 90% (Table 27). The remaining three taxa had an establishment probability of 25% or less. There was considerable imprecision in some of these estimations, given the relatively high standard deviations of predicted probability of establishment. This was due in large part to greater relative importance of hypoxia tolerance scores and low numbers of tropical islands/island groups on which they are established (0 for six taxa, 1 for two taxa, and 2 for one taxon). Nevertheless, this procedure illustrates how the modeling method can be applied to provide a general estimate of establishment likelihood for taxa of potential concern.

Table 24. Summary of the numbers of introduced and established nonindigenous fishes on Guam and the Hawaiian Islands.

| Island or island group | Number of nonindigenous fish introduced[a] | Number of nonindigenous fish established (percentage of total introduced)[b] | Number established on "other tropical Pacific islands"[c] | Number established on "other tropical islands"[d] |
|---|---|---|---|---|
| Guam | 25 | 13 (52%) | 15 | 18 |
| Hawaii | 70 | 46 (66%) | 31 | 37 |
| Guam and Hawaii[e] | 80[f] | 49[g] (61%) | 35 | 42 |

[a] Total number of nonindigenous fish species or taxa reported as introduced into inland waters, including those that are considered established combined with those that have been documented as introduced or occurring in the wild, but not known to have established (reproducing) populations.

[b] These values represent total number of nonindigenous fish species or taxa that have one or more populations in inland waters that are considered established (reproducing).

[c] These values represent total number of nonindigenous fish species or taxa that are known to have been introduced (established and not established) to the location identified in column #1 (i.e., either Guam, Hawaii, or both) that are also documented as having been introduced and currently considered established on one or more other tropical Pacific islands. (Note: additional nonindigenous fish species, never introduced to Guam or Hawaii, are established on other tropical Pacific islands, but these additional taxa are not considered in this tabulation).

[d] These values represent total number of nonindigenous fish species or taxa that are known to have been introduced (established and not established) to the location identified in column #1 (i.e., either Guam, Hawaii, or both) that are also documented as having been introduced and currently considered established on one or more other tropical islands throughout the globe. (Note: additional nonindigenous fish species, not known to have been introduced to Guam or Hawaii, are established on other tropical islands, but these additional taxa are not considered in the tabulation).

[e] Treating Guam and the Hawaiian Islands as a single geographic unit; the values in this row relate to the total number of nonindigenous fish species or taxa documented from either Guam, Hawaii or both (e.g., a species that may have been introduced to Guam, but not to Hawaii, would be treated as introduced to Guam and Hawaii)

[f] It was determined that 15 of the 80 introduced nonindigenous fish species/taxa tallied have been introduced to both Guam and Hawaii.

[g] It was determined that 10 of the 49 total number of established species/taxa are established on both Guam and Hawaii.

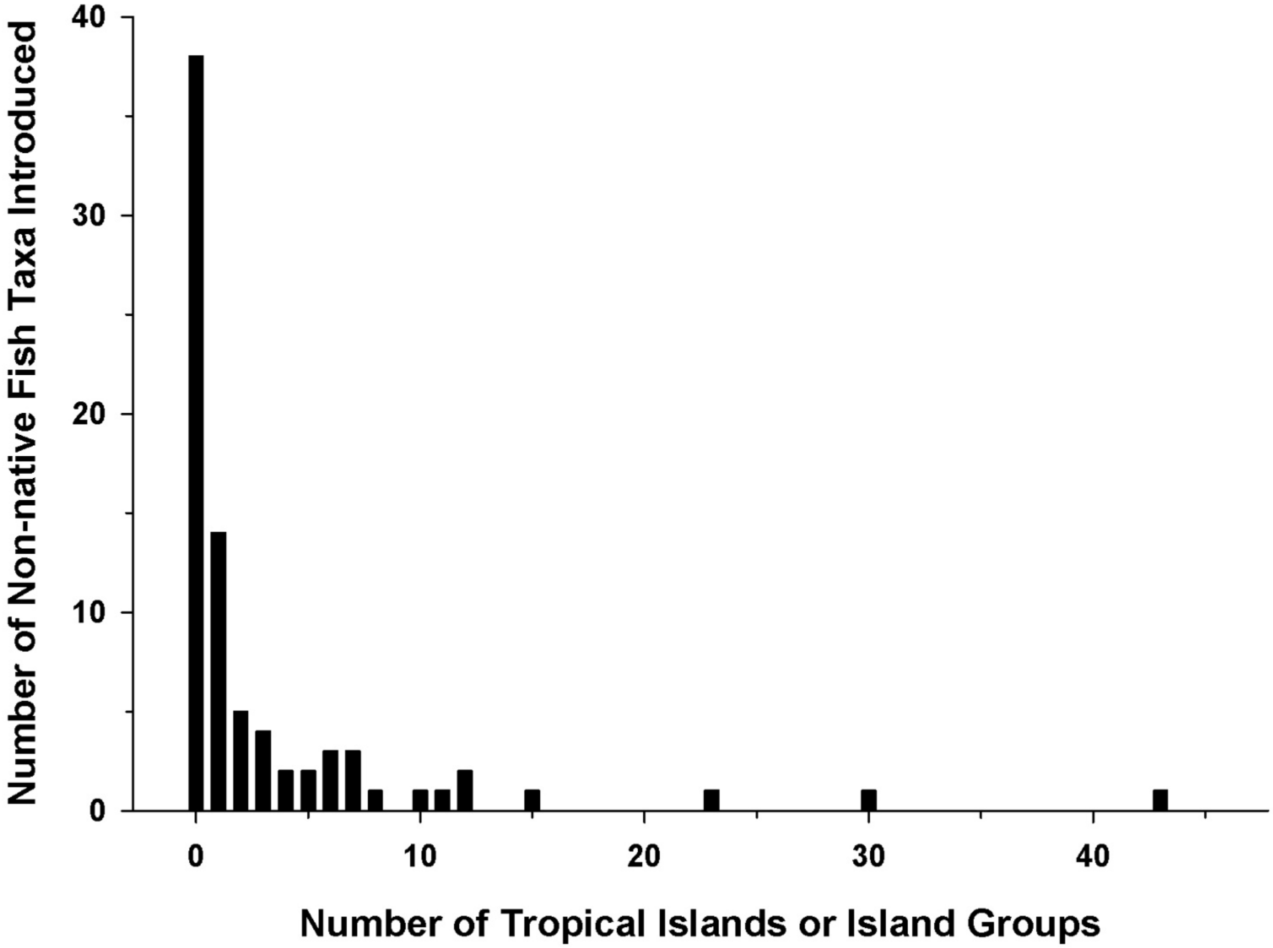


Figure 19. Frequency distribution of nonindigenous freshwater fish species introduced to Guam, Hawaii, or both, and the number of other tropical islands where they are established globally. This graph relates to the history variable used in risk analysis, i.e., prior establishment success.

Table 25. Models of establishment success of nonindigenous inland fish species introduced into Hawaii and Guam since the late 1800's were compared using an information-theoretic approach. [The model with the lowest $AIC_c$ and highest Akaike weight had the most support. $AIC_c$ balances model precision and bias. Akaike weights indicate relative support for each model and sum to one. Only models with an Akaike weight ≥ 0.01 are shown. The best *a priori* model included an effect of taxonomic affinity (family) and prior establishment success on tropical islands or island groups other than Hawaii and Guam (history). Seven *a posteriori* models were created, each containing a unique combination of the variables climate profile, hypoxia tolerance, and salinity tolerance added to our best *a priori* model. The new best model included effects of taxonomic affinity (family), prior establishment success on tropical islands or island groups other than Hawaii and Guam (history), and hypoxia tolerance. The second, third and fourth best models were minor variations of our best model. The third best model overall was our best *a priori* model. We did not include Model 29 from Table 23 in this model comparison since that model was two steps removed from being *a priori*.]

| Model number | Model | Number of. parameters in model | Log-likelihood | $AIC_c$ | $\Delta AIC_c$ | Akaike weight |
|---|---|---|---|---|---|---|
| 23 | Family + history + hypoxia tolerance | 5 | -39.2382 | 89.28725 | 0 | 0.587 |
| 27 | Family + history + hypoxia tolerance + salinity tolerance | 7 | -38.7221 | 92.9998 | 3.712554 | 0.092 |
| 19 | Family + history | 3 | -43.4619 | 93.23956 | 3.952312 | 0.081 |
| 25 | Family + history + climate profile + hypoxia tolerance | 7 | -38.9803 | 93.51617 | 4.228921 | 0.071 |
| 10 | Family + history + reproductive guild + environmental tolerance | 6 | -40.7468 | 94.64419 | 5.356942 | 0.040 |
| 15 | Family+ history + pathways | 4 | -43.1532 | 94.83976 | 5.552514 | 0.037 |
| 18 | Family + history + length | 6 | -40.8552 | 94.86112 | 5.573872 | 0.036 |
| 24 | Family + history + salinity | 5 | -42.7962 | 96.40313 | 7.115879 | 0.017 |
| 6 | Family + history + pathways + reproductive guild + environmental tolerance | 7 | -40.6548 | 96.86508 | 7.577831 | 0.013 |
| 22 | family + history + climate profile | 5 | -43.2218 | 97.25438 | 7.967138 | 0.011 |
| 28 | family + history + climate profile + hypoxia tolerance + salinity tolerance | 9 | -38.6093 | 97.79007 | 8.502822 | 0.008 |

Table 26. Parameter estimates from the best model of establishment success of nonindigenous inland fishes in Hawaii and Guam. [Included is the estimate for the fixed intercept (no family effect) as well as estimates for each family (random intercept)]

| Variable | Level | Parameter estimate | Standard error |
|---|---|---|---|
| Intercept | Fixed | -0.24 | 0.90 |
| Islands (history) | Continuous | 0.45 | 0.19 |
| Hypoxia tolerance | 2 | -2.56 | 1.18 |
| Hypoxia holerance | 3 | 2.36 | 1.71 |
| Adrianichthyidae | Random | -0.65 | |
| Anguillidae | Random | -0.88 | |
| Anostomidae | Random | -1.49 | |
| Aplocheilidae | Random | -0.54 | |
| Ariidae | Random | -1.49 | |
| Belonidae | Random | 2.79 | |
| Blenniidae | Random | 1.26 | |
| Callichthyidae | Random | 0.24 | |
| Centrarchidae | Random | 2.54 | |
| Centropomidae | Random | -0.65 | |
| Channidae | Random | -0.21 | |
| Characidae | Random | -1.62 | |
| Cichlidae | Random | 3.76 | |
| Clariidae | Random | 0.56 | |
| Clupeidae | Random | 1.02 | |
| Cobitidae | Random | 0.01 | |
| Cyprinidae | Random | 0.20 | |
| Fundulidae | Random | -0.54 | |
| Gobiidae | Random | 1.26 | |
| Ictaluridae | Random | 0.14 | |
| Kuhlidae | Random | -1.49 | |
| Loricariidae | Random | 0.20 | |
| Lutjanidae | Random | 1.26 | |
| Mochokidae | Random | -0.54 | |
| Moronidae | Random | -1.49 | |
| Nothobranchiidae | Random | -0.54 | |
| Osphronemidae | Random | -3.48 | |
| Osteoglossidae | Random | -0.54 | |
| Pangasiidae | Random | -3.42 | |
| Plecoglossidae | Random | -1.49 | |
| Poeciliidae | Random | 2.11 | |
| Salmonidae | Random | -1.76 | |
| Synbranchidae | Random | 0.24 | |

Table 27. Predicted establishment probability using best-fit model of selected fish taxa not known to be currently established in Hawaii or Guam. [Taxa on Guam Division of Aquatic and Wildlife Resources (DAWR) white list (permitted for importation) indicated by shading]

| Family | Scientific name | Common name | Tropical island groups on which established | Hypoxia tolerance score | Predicted establishment probability | Standard deviation |
|---|---|---|---|---|---|---|
| Callichthyidae | *Hoplosternum littorale* | brown hoplo | 0 | 3 | 0.92 | 0.17 |
| Mastacembelidae | *Mastacembelus/Macrognathus* spp. | spiny eels | 1 | 2 | 0.25 | 0.36 |
| Cyprinidae | *Mylopharyngodon piceus* | black carp | 0 | 2 | 0.07 | 0.11 |
| Cyprinidae | *Pimephales promelas* | fathead minnow | 0 | 2 | 0.07 | 0.11 |
| Polypteridae | *Polypterus* spp. | bichirs | 0 | 3 | 0.75 | 0.37 |
| Lepisosteidae | *Lepisosteus/Atractosteus* spp. | gars | 0 | 3 | 0.75 | 0.37 |
| Osteoglossidae/Arapaimidae | *Scleropages/Heterotis* spp. | Australasian/African bonytongues | 2 | 3 | 0.74 | 0.36 |
| Notopteridae | *Notopterus/Chitala* spp. | featherbacks | 1 | 3 | 0.77 | 0.35 |
| Clariidae | *Heteropneustes* spp. | stinging or air-sac catfishes | 0 | 3 | 0.95 | 0.11 |

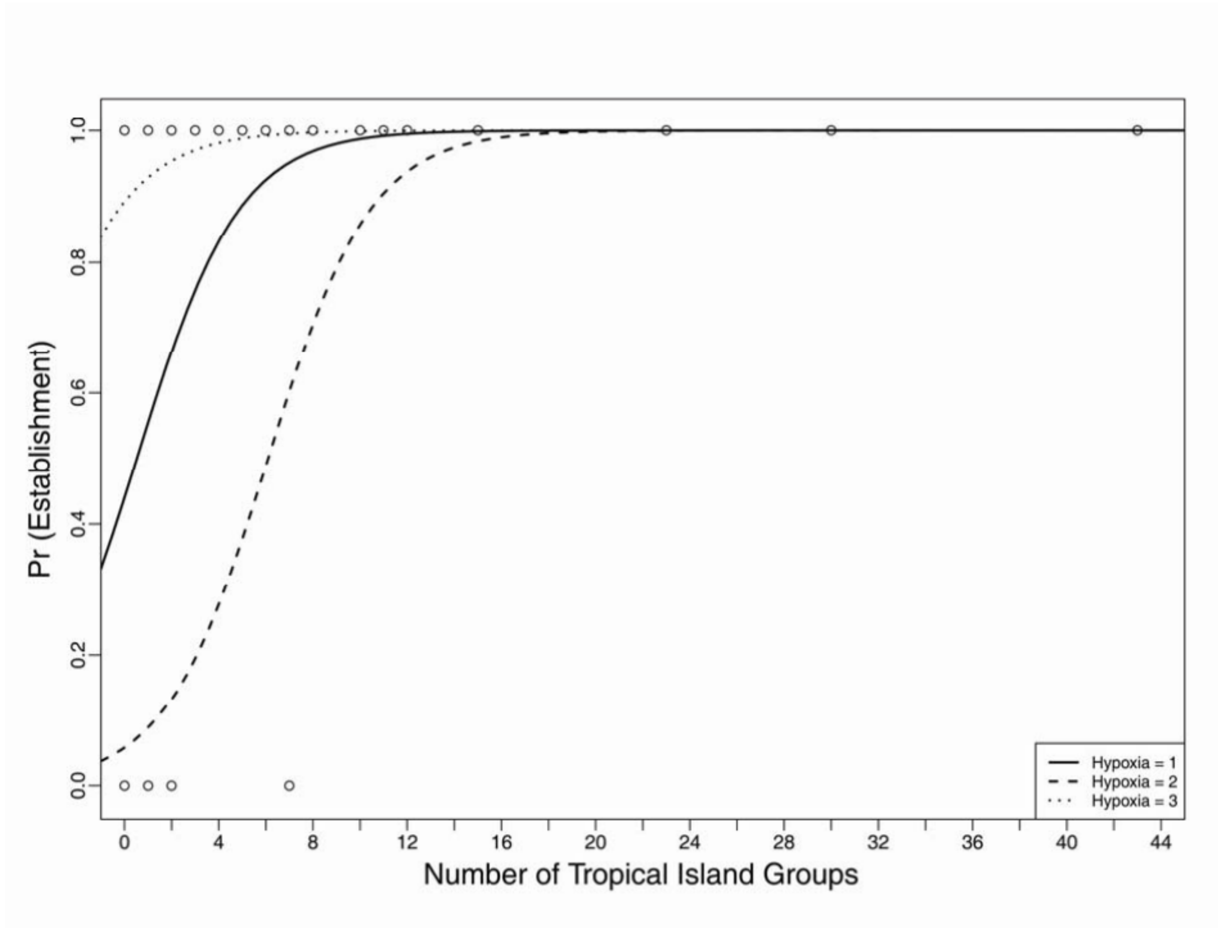


Figure 20. Probability of establishment of nonindigenous inland fishes introduced into Hawaii and Guam as a function of (1) number of tropical islands or island groups, excluding Hawaii and Guam, on which a species is established and (2) hypoxia tolerance. A fixed intercept is used to remove family effect. Species or taxa with a hypoxia tolerance score of 1 (solid line) are intolerant of low oxygen levels; species with a score of 2 (dashed line) are moderately tolerant, and species with a score of 3 (dotted line) are air-breathers. Open circles represent the number of tropical islands or island groups on which a species is known to be established. Number of islands or island groups on which a species was established, excluding Guam and Hawaii, ranged from 0 to 43. Of the 80 nonindigenous fish species or taxa introduced into Guam and Hawaii, 38 were not established on any other tropical islands, 14 were established on one other tropical island or island group, five were established on two, four were established on three, and 19 were established on > 3 other tropical islands or island groups.

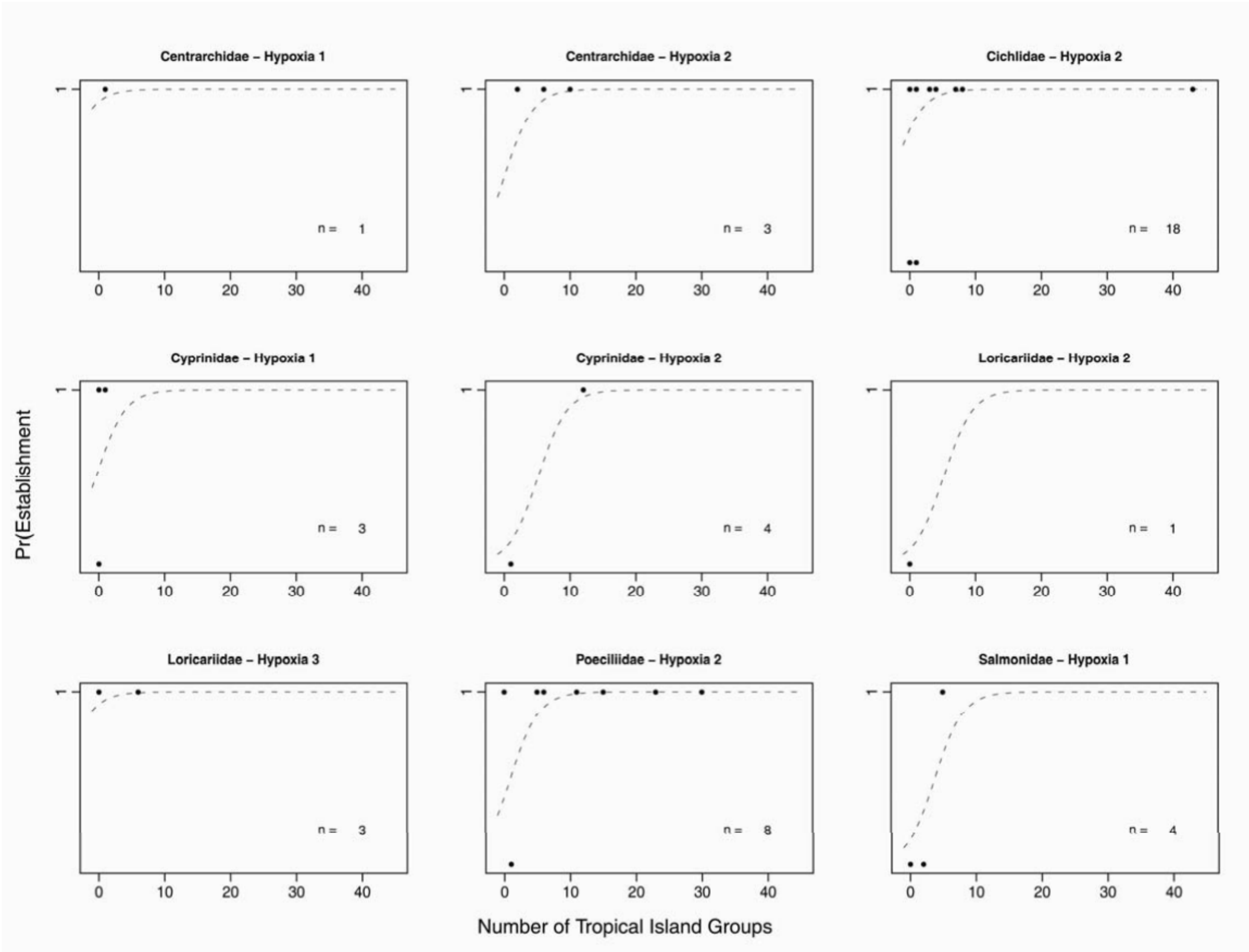


Figure 21. Probability of establishment of nonindigenous inland fishes introduced into Hawaii and Guam as a function of (1) number of tropical islands or island groups, excluding Hawaii and Guam, on which a species is established and (2) hypoxia tolerance, with family effect used as intercept. Only families represented by > 3 species are shown (n = the number of species for a given family:hypoxia tolerance combination).

## Discussion

Our best model of establishment success can be used to predict establishment probability of nonindigenous fish species or taxa introduced or likely to be introduced into Hawaii or Guam in the future. Such an application of the model would require that data be gathered for each particular taxon to be tested. This would include data necessary to reliably assign a score for each of the variables in our best model: (1) history (number of tropical islands or islands groups on which the species is established excluding Hawaii and Guam), (2) hypoxia tolerance score, and (3) family (taxonomic affinity).

Ultimately, authorities (e.g., resource managers, legislators) must define an acceptable level of risk that considers the benefits of importing or using a nonindigenous fish against the likelihood that it may become invasive and the potential magnitude of its unintended environmental, economic, and social costs. Once an acceptable level of risk is determined and the necessary data gathered to reliably score model variables, the model could be used to estimate whether the predicted probability of establishment was above, below, or equal to the accepted level of risk. Species above an accepted level of risk might be considered for removal from a permitted (white) list or added to a prohibited (black) list. For example, if the accepted level of risk was an establishment probability of 0.44, perhaps all air-breathing fish species would be prohibited (based on Fig. 20); species intolerant to low dissolved oxygen levels (hypoxia tolerance score of 1) might only be permitted if they were not established on any other tropical island or island group; and species with a hypoxia tolerance score of 2 might only be permitted if they were established on fewer than 6 other tropical islands or island groups.

Our results, which estimated a higher establishment probability for species with a hypoxia tolerance score of 1 than for species with a score of 2, were counterintuitive. We expected species with a score of 1 to have the lowest establishment probability. Perhaps the reason species with a score of 1 had a higher estimated establishment probability is that most stream habitats in Hawaii and Guam may have high dissolved oxygen levels because of swift currents. Restated, an abundance of habitats with high dissolved oxygen levels may provide plentiful opportunities for establishment of species that require high dissolved oxygen levels.

Nevertheless, the counterintuitive results related to hypoxia tolerance might also reflect a shortcoming of the model or the data. Some of the assigned variable scores used in the model were heavily based on expert opinion, perhaps influenced by knowledge of similar species rather than rigorous published research about a particular target species. Modeling efforts historically have (and perhaps always will) serve to highlight gaps in existing knowledge of systems and the ecology and precise life-history attributes of various organisms. Our model was no different in that regard. Available information on many fish species makes it difficult to clearly distinguish between a species' physiological tolerance limits compared to environmental preferences and requirements, much less their ecological optima. Consequently, the ecological or physiological variables incorporated into a model may reflect absence of knowledge about species-specific values for certain life-history and ecological variables rather than absence of a relationship between these variables and establishment success. A history of being established on other tropical islands or island groups did appear to be strongly correlated with establishment success and similar relationships have been reported by other authors for various taxa. The relationship we detected here is likely real, albeit not as revealing or enlightening about the biology of the species and the system studied as we might prefer. That air-breathing species have a high estimated establishment probability was also expected, and lends additional support to our model.

An additional problem in attempting to model and predict establishment is the fact that there is a fair amount of uncertainty with regard to basic knowledge about fish introductions and the status of nonindigenous fish populations. For example, it is likely that some nonindigenous fish species have been introduced to Hawaii and Guam that were never documented. In addition, such unrecorded nonindigenous species could be established in Hawaii and/or Guam, but as yet remain undetected. Relative to the many hundreds to thousands of fish species in the ornamental fish trade, few have been documented as introduced into the wild in Hawaii and Guam, and even fewer of these have become established. That only two fish species in our analysis (both estuarine) that were documented to have been introduced into Hawaii by means of ballast may seem somewhat unexpected given the volume of ship traffic to these islands. Perhaps other fish species have been introduced by means of this vector but failed to establish and were never detected (or if established remain undetected or at least unreported). However, because most ballast water transported to these insular areas is of high salinity, relatively stenohaline freshwater or brackish water species would likely have low levels of survivorship during long periods of transport in this medium. Historical records of fish species introduced intentionally along other pathways, such as stocking for sport fishing, are presumed to be known with a greater degree of certainty than introductions by means of accidental pathways (e.g., ballast water and contaminants).

Propagule pressure has been reported as an important variable in estimating establishment success (Marchetti et al. 2004a, b; Lockwood et al. 2005; Rixon et al. 2005; Colautti et al. 2006; Duggan et al. 2006; Moyle and Marchetti 2006; Copp et al. 2007; Gertzen et al. 2008). Propagule pressure may be generally defined as the number of individual fish of a given species introduced into an area (although life-history attributes such as fecundity or parental care can also be correlates). Probability of establishment is expected to increase as the number of individuals that are released increases. Unfortunately, in most cases for freshwater fishes in Hawaii and Guam, few data exist on the number of individuals of a given species that have been released into the wild for some of the most likely pathways of introductions that lead to establishment (e.g., the aquarium trade). To better assess risk of species and pathways, a suggested approach for future analyses would be to gain greater knowledge about propagule pressure, especially for areas where important information gaps exist (e.g., prohibited importations that are undetected, contaminants in legal shipments, etc.).

Screening of nonindigenous species imported into Hawaii and Guam using a predictive model such as ours may reduce the likelihood of additional invasive species becoming established in either locale. Aquaculture and the aquarium trade are the primary pathways of introduction for nonindigenous fishes in Hawaii and Guam. These pathways reflect the intentional importation of fish. As such, they may be under greater management control than some other pathways and more conducive to regulation by means of a white list guided by a predictive model.

# Management Alternatives, with Preexisting Conditions, Potential Actions, and Mitigation Measures for Micronesia

## Background

In the U.S., the term “best management practice” (BMP), as applied to environmental management (specifically, pollution control), originated in the Clean Water Act of 1972, although it was not explicitly defined in that legislative document. BMPs have been widely applied to complex environmental problems, generally in a context-specific manner and often lacking imperfect knowledge about the outcome of management actions under different settings. By definition, BMPs are transitory; although in principle there can only be one “best” practice, many are likely to be “better” than a range of others, and incremental improvements may occur over time as new knowledge is attained and protocols, procedures, or practices change (Clay 2008). Increasingly, the term BMP refers to “better management practices.” Conceptually, for complex problems (such as prevention or mitigation for invasive species), BMPs are best regarded as an adaptive learning process rather than an exclusively prescriptive approach (Measham et al. 2007).

As an objective, policy-neutral, science-based agency, the USGS has no management or regulatory authority. Therefore, the USGS refrains from making recommendations that target specific management or policy actions, and terminology such as “best management practice” or “BMP” is not used. Herein, management alternatives are provided with an implicit understanding that all options have not been thoroughly vetted and strategic actions may be warranted and modified over time as new information becomes available. Many existing sources provide baseline information on strategies for mitigating deleterious ecological or socioeconomic effects of invasive species; the information provided in this report is based on sources considered reliable (e.g., Wittenberg and Cock 2001; Tucker and Hargreaves 2008; Henderson and Bomford 2011).

This document provides management alternatives intended to help prevent, limit, or mitigate impacts of invasive freshwater animal species in the region of Micronesia, with emphasis on fishes, turtles, frogs, and macroinvertebrates. New practices or modifications of existing ones are intended to compliment other management options provided by Federal agencies to address additional organisms representing different taxonomic groups, their habitats, and associated pathways (e.g., terrestrial and marine plants and animals, pathogens, and diseases).

## Summary of Management Alternatives

Management can best focus on the following aspects of the sequential invasion process: (1) preventing introductions from occurring; (2) detecting incursions at an early stage; and (3) rapidly eradicating newly found nonindigenous organisms and/or mitigating the worst effects of established or reproducing invasive populations (Kraus and Duffy 2010).

(1) Prevention requires the identification of all pathways and then screening major pathways so as to exclude importation of species most likely to become invasive. This is typically accomplished by screening for animals at the port of origin, and also port-of-entry screening of pathways or products thought or known to be at high risk for harboring nonindigenous aquatic animals.

(2) Rapid-response programs typically involve systematic attempts to detect new incursions followed by programs to eradicate (or at least contain) the worst species so detected.

(3) Long-term mitigation is usually focused on areas of high value or importance that need protection, such as national parks, undisturbed natural streams, or other unique ecosystems. For Guam and other Pacific islands, areas needing protection may best be identified through “ecosystem prioritization” (Jenkins et al. 2009). Long-term mitigation may also involve attempts to control particularly harmful species over much of their invaded ranges.

The following list (Table 28) provides management alternatives that are intended to assist in the prevention, limitation, or mitigation for possible impacts of invasive and other nonindigenous freshwater animals, with specific emphasis on Guam (although many of the items might equally apply to other governments of Micronesia, as well as other commercially linked regions). The subsequent discussion addresses the following main strategies and topics: (1) prevention/pathway disruption; (2) early detection; (3) contingency plans/rapid response; (4) long-term management; and (5) research needs. Action-specific recommendations and priority levels are not implied in keeping with the aforementioned policy and management-neutral position of the USGS. The list is followed by more detailed information and the rationale for each of the strategies. These management options are provisional in the sense that the science of invasive species is a growing and rapidly changing field. Moreover, local conditions are dynamic. For example, relevant information may become available in the future, or events and field conditions may change that necessitate adjustments of how to best manage certain nonindigenous species or groups of species and particular pathways of introduction. Globally, bioinvasions are highly complex and management strategies require sophisticated levels of coordination (Ruiz and Carlton 2003; Henderson and Bomford 2011). As such, management alternatives as outlined here are considered to be only general guiding principles, and implementation of precautionary as well as post-invasion approaches will require a substantial degree of cooperation among all sectors involved in commerce throughout Micronesia.

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to | | |
|---|---|---|---|---|---|
| | | | DoD | Non-DoD | Foreign |
| 1 | Inspection program: Development of an international inspection and monitoring program in which nations coordinate monitoring for invasive species and attempts to prevent their export as well as import. | Prevention/pathway disruption | X | X | X |
| 2 | Inspection program: Improvement and expansion of existing documentation and record keeping on the types and numbers of imported aquatic species, including imports from both domestic and foreign sources. Such documentation requires complete and accurate identification of animals to species level, numbers of specimens, purposes, sources, and pathways. | Prevention/pathway disruption | X | X | |
| 3 | Inspection program: Assurance that border agents and wildlife inspectors have necessary training and knowledge to identify all or most aquatic animal families, genera, and species, including those prohibited by Federal laws and also taxa permitted under Guam's White List. | Prevention/pathway disruption | X | X | |
| 4 | Inspection program: Additional personnel and training of wildlife inspectors and/or implementation of a quarantine system so that most shipments of live wildlife can be inspected. | Prevention/pathway disruption | X | X | |
| 5 | Inspection program: Augmentation, expansion, and/or replacement of existing radiographic equipment used to screen imports for live aquatic animals. | Prevention/pathway disruption | | X | |
| 6 | Inspection program: Inspection of all international packages and increased efforts to inspect a greater percentage of domestic mail. | Prevention/pathway disruption | X | X | |

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to | | |
|---|---|---|---|---|---|
| | | | DoD | Non-DoD | Foreign |
| 7 | Survey questionnaires: Survey(s) of incoming military and construction workforce to learn about aquatic animal pets. Questions might include the types and numbers of aquatic animal pets currently owned; which pets, if any, are intend to be transported to Guam; and, regarding unwanted pets, if owners would be likely to release animals into the wild or would they be willing to relinquish pets to pet shops or other authorities. | Prevention/pathway disruption | X | X | |
| 8 | Education/outreach—international conferences: Such venues provide a means to maintain open communication and improve diffusion of knowledge of new advances in invasive species biosecurity, covering such themes as prevention/pathway disruption, early detection, management, eradication and control. To increase participation, various Pacific island governments and institutions could be engaged by encouraging different venues among the major islands. | Long-term management | X | X | X |
| 9 | Education/outreach: Development and distribution of brochures, posters, bumper stickers, and other forms of print and mass media that provides information on invasive aquatic animals, their identification, the harm that these animals can cause, warnings against releasing pets into the wild, and warnings against transporting illegal or potentially harmful aquatic species. Target groups might include military and civilian families intending to move to Guam, as well as current Guam residents, private businesses, public organizations, schools, and others. | Prevention/pathway disruption & early detection | X | X | X |

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to DoD | Non-DoD | Foreign |
|---|---|---|---|---|---|
| 10 | Education/outreach: Development of a short video describing potential harm caused by nonindigenous invasive species and warning against their transport or release. Such a video could be shown on incoming commercial and military passenger flights and passenger ships. | Prevention/pathway disruption | X | X | |
| 11 | Education/outreach: Development of education programs that target children by providing interactive school presentations that illustrate the impacts that nonindigenous species can have and discouraging release of pets. | Prevention/pathway disruption | | X | |
| 12 | Education/outreach: Encouragement to pet stores and garden retail outlets to participate in the Habitattitude program (*http://www.habitattitude.net/*), a partnership between commercial industry and the Aquatic Nuisance Species Task Force that increases consumer awareness and engages businesses and the public to prevent the release of invasive species. | Prevention/pathway disruption | X | X | |
| 13 | Education/outreach: Assistance and encouragement for pet stores to identity captive stocks with valid scientific names, including provisioning vendors with printed material on the subject and consultation with qualified experts. | Prevention/pathway disruption | | X | |
| 14 | Survey questionnaires: Surveys of pet store customers that include questions about the types and numbers of pet aquatic animals currently owned, whether any unwanted pets have ever been released into the wild; and, regarding future unwanted pets, would owners be likely to release animals into the wild or be willing to turn pets over to pet shops or other authorities. | Prevention/pathway disruption | X | X | |
| 15 | Education/outreach: Website development to disseminate information about native and invasive species. | Prevention/pathway disruption | X | X | |

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to DoD | Applies to Non-DoD | Applies to Foreign |
|---|---|---|---|---|---|
| 16 | Education/outreach: Establishment of programs that provide information on alternatives to releasing unwanted pets, possibily including arrangements for pet stores to accept unwanted pets and/or establishing periodic “Amnesty Days” for the public to surrender unwanted or illegal pets. | Prevention/pathway disruption | X | X | |
| 17 | Expert panel(s): Panel(s) of experts to periodically assess operations at borders that involve screening of imported aquatic animals, identification of any existing or potential needs and problem areas in the screening process, assessment of inspector training issues and needs, and review of permitted species. | Prevention/pathway disruption | X | X | X |
| 18 | Management/regulation of aquaculture industry: Establishment and maintenance of a database of active and former aquaculture facilities that can be used by management resource agencies and invasive species researchers. Database to include location and contact information of all facilities, types and numbers of aquatic species held, and how and where live animals are distributed. | Prevention/pathway disruption | | X | X |
| 19 | Management/regulation of aquaculture industry: Routine inspections of aquaculture facilities and farms to assess biosecurity features, focusing on escape risk and type(s) of stock being cultured. This may include evaluation of design and condition of facilities and ponds (e.g., pond location, status of perimeter berms and fences, inlets and outlets); assessment of live aquatic animals cultured, health and status of breeding stocks, and whether any are contaminated by unwanted or harmful species; assessment of equipment; and evaluation of personnel training and determination if additional training is needed. | Prevention/pathway disruption | | X | X |

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to DoD | Applies to Non-DoD | Applies to Foreign |
|---|---|---|---|---|---|
| 20 | Management/regulation of aquaculture industry: Promotion of the use of triploid, sterile, male fish or only native species in aquaculture. Higher priority for any stock that is distributed live to less secure facilities. | Prevention/pathway disruption | | X | X |
| 21 | Management/regulation of live food markets: Enforcement of existing regulations and/or establishment of new procedures to minimize allowing retail live food markets on Guam and other Pacific islands to supply customers with live, potentially invasive non-native aquatic animals; encouragement to have vendors provide food fish or other aquatic animals fresh, on ice, at time of sale. | Prevention/pathway disruption | X | X | |
| 22 | Establish or strengthen existing programs for monitoring and sampling inland water bodies on Guam and other Pacific islands for the purpose of detecting new or expanding populations of invasive and other nonindigenous aquatic animals. Form and support teams to regularly visit markets and seafood restaurants to document presence of live nonindigenous aquatic animals, including any illegal species. Samples of nonindigenous aquatic species collected, preserved, and voucher specimens deposited in repositories of major scientific museums (e.g., the University of Guam in Mangilao; Bishop Museum in Honolulu). Discoveries of new nonindigenous populations reported to a rapid response team and, if appropriate, information provided to news outlets to inform and advise the public. | Early detection | X | X | X |
| 23 | Development and advertisement of a reporting process for military personnel and private citizens who suspect that they have captured or detected a new or uncommon nonindigenous aquatic species. | Rapid response | X | X | X |

Table 28. Summary of management alternatives for nonindigenous freshwater animals. [DoD, Department of Defense; Non-DoD, local, territorial, and other civilian regulatory and/or management agencies in Guam); Foreign, other sovereign governments of Micronesia]

| No. | Management Alternative | Category | Applies to | | |
|---|---|---|---|---|---|
| | | | DoD | Non-DoD | Foreign |
| 24 | Establishment of team(s) led by qualified experts who can rapidly respond and attempt to eradicate any newly discovered wild populations of invasive aquatic species. This requires training, adequate equipment, and development of appropriate protocols for control or eradication. | Rapid response | X | X | X |
| 25 | Ecosystem prioritization: Assessment of drainages and water bodies within and outside military reserves so as to prioritize aquatic and wetland ecosystems in terms of their biological significance. Such information is useful for determining areas to focus monitoring, control, and/or eradication efforts. | Long-term management | X | X | |

## Pathways Assessment with Existing Management Practices

In this section we provide an assessment by pathway of the current status of conditions on Guam and elsewhere in Micronesia, relevant practices currently in place, and the prognosis for future change that may be directly or indirectly associated with the military buildup.

In the following pathway assessment, the prognosis for each pathway includes a qualitative rating or estimation of the overall risk, including the level of uncertainty using criteria established by the Risk Assessment and Management Committee of the Aquatic Nuisance Species Task Force (RAM-ANSTF 1996). Estimated level of risk of each element or pathway is rated as “low,” “medium,” or “high,” and levels of uncertainty are “very certain,” “reasonably certain,” “moderately certain,” “reasonably uncertain,” and “very uncertain.” The analysis relies on the current state of available information, and resulting risk assessments are intended only as general guidelines for what to expect for future conditions pertaining to each pathway, and how the implementation of alternative management actions may help to mitigate by preventing further establishment or spread of nuisance aquatic species.

### Aquarium Trade and Related Commerce in Ornamental Aquatic Animals

Ornamental commerce involves the aquarium trade industry, which includes retail merchants, regional wholesalers, import and export wholesalers, and related businesses that raise or sell aquatic animals for captivity as pets or “ornamentals” (e.g., koi for private and public water-garden ponds.), and consumers, mainly pet hobbyists, who buy and maintain live aquatic animals in captivity. A large number and wide diversity of freshwater fishes and other aquatic organisms (e.g., crustaceans and mollusks) are distributed and marketed worldwide as ornamentals. As a result, this pathway is one of the primary means by which aquatic nonindigenous species have become introduced and established in both freshwater and marine environments throughout the world (Courtenay and Stauffer 1990; Courtenay 1999; Fuller et al. 1999; Eldredge 2000; Fuller 2003; Padilla and Williams 2004; Rixon et al. 2005; Calado and Chapman 2006; Duggan et al. 2006; Gertzen et al. 2008). Padilla and Williams (2004) estimated that perhaps one-third of the world’s worst aquatic invasive species are aquarium or ornamental species.

The aquarium pet trade is the pathway by which a large number and variety of different nonindigenous fishes and other aquatic animals are imported to Guam (Table 14) and to other Pacific islands. Over the last several decades, this pathway has also (and will likely continue to) lead to the introduction of certain fishes into the wild in Guam and other Pacific islands, and was the primary pathway of introduction for many aquatic animals now established in Hawaii (Maciolek 1984; Eldredge 2000; Yamamoto and Tagawa 2000). The aquarium trade is complex and is closely tied to other major pathways, such as aquaculture and stocking contaminants. For example, some fishes, crustaceans, and mollusks, especially snails, may be transported and enter new areas accidentally as contaminants or stowaways in shipments of other aquatic ornamental animal and plant species that are being purposely imported (Lin et al. 2006).

With the aquarium trade considered as the general pathway, there are different sub-pathways or vectors by which aquatic animals and plants become introduced to new places. One of the more common modes by which ornamental species become established is direct release of animals by pet owners. Reasons for the disposal of pet fish are varied and include the following (Gertzen et al. 2008):

- Aggressive behavior
- Large size
- Frequent illness
- Rapid reproduction
- Other reasons, such as owner(s) that are moving, bored with pets, or tired of maintenance

Other pathways and vectors that are either a subset or closely linked to the aquarium pet trade include escapement from holding facilities, especially outdoor ponds, raceways, or other structures used for holding or captive breeding. Sites where such escapements of fish commonly occur are commercial ornamental fish farms. For example, in Florida and other warmer parts of the United States, a number of species are known to have become established or probably became established in this manner (Courtenay and Stauffer 1990; Courtenay 1994; Courtenay 1999; Fuller et al. 1999).

### Present Condition: Aquarium Pet Owners

Aquarium pet owners and other pet hobbyists are consumers, private citizens that commonly play important and varied roles in the aquarium trade pathway. Functioning as vectors, pet owners are known or reputed to hand carry or otherwise transport a small number of live freshwater fish or other aquatic animals to Guam and other Pacific islands. Citizens may be residents or nonresidents. This pathway may include any live aquatic animals considered to be personal pets or gifts provided to friends or family members. Animals are typically transported in this pathway by one of the following methods: (1) hand-carried or with checked-in luggage on airlines or by maritime vessel; or (2) packaged and shipped by means of private-sector couriers or the U.S. Postal Service. This pathway is distinguished from the commercial retail industry because it is small-scale, relatively sporadic, and typically not-for-profit.

The current number of private citizens that carry or send pet aquatic animals to Guam is unknown, as is information pertaining to the degree to which non-commercial shipments containing live animals arrive through this pathway. It is assumed to represent a small proportion, relative to the aquarium industry, of the total number of aquarium fishes and other aquatic pets that enter Guam or other Pacific islands. The extent to which any nonindigenous freshwater fishes and other aquatic animals established in the wild on Guam that may have been introduced by means of this pathway is unknown.

### Present Condition: Retail Sales

A few nonindigenous freshwater fishes and other aquatic animals established in the wild on Guam—because of their wide distribution and popularity as pets—are presumed to have originated by means of the aquarium or ornamental pet trade. These particular species may have escaped from holding facilities or, more likely, were intentionally released.

Many freshwater fishes and other aquatic animals imported and sold in the aquarium trade are misidentified, partly because many taxa are difficult even for experts to positively identify to species level. In addition, some species that are legal to import are similar in appearance to species that are illegal. Consequently, lists of imported species maintained by government agencies and businesses associated with the aquarium industry likely contain incorrect species identifications. This situation increases the risk that certain harmful or illegal aquatic animals will be imported, unintentionally and without the knowledge of regulators. According to Gertzen et al. (2008) there is little regulation of the aquarium trade in terms of restricting potentially nuisance nonindigenous aquatic species. Molecular tools may be useful for identification and may also serve to recognize taxa in the live animal or plant trade that are mislabeled (Thum et al. 2011).

Guam currently has two retail pet stores that import and sell live freshwater and marine fishes, invertebrates, plants, and locally caught turtles: Little Wangz Petlife in Harmon, and

Feathers ‘n Fins (*http://www.feathersnfins.com/*) in Hagåtña. Additionally, a vendor who does not have a physical retail shop occasionally sells live aquarium fish, plants, snails, and turtles at the flea market in Dededo. The garden center at the U.S. Naval Base was also visited and, at the time of our visit, had live freshwater plants for sale; a few fish (*Poecilia reticulata*) and snails were observed in some of the containers, but appeared to be contaminants of the water and plant stock. Most freshwater ornamental fishes for sale in the stores are imported. The primary sources of aquarium fish shipped to Guam are in Malaysia, but fish are apparently also shipped directly from both Florida and Japan (Christy et al. 2007b). Additionally, a clerk at one shop told us that they obtain a few locally-reared fishes (guppies and platyfish) from one or a few individuals who culture the fish in outdoor ponds, but this information is unverified.

Customs records and statistics maintained by the U.S. Fish and Wildlife Service indicate that the volume of imports to Guam is moderate. However, due to a variety of reasons, we were unable to obtain detailed information on types and numbers of ornamental freshwater fishes imported into Guam annually or volume of sales. Augmenting the available information, our visits to both of the “brick-and-mortar” pet stores on the island confirmed that a wide variety of species were for sale. Based on visits to the stores in 2010, we compiled a partial list of the types of live fish available for sale (Table 29). This list includes approximately 80 to 90 species or strains representing about 18 families. We suspect that the number of different species imported varies among years and certain seasons, depending on availability of stock and changing consumer demand. The typical method for commercial shipment of live ornamental fish is by means of airplane flights, with fish confined within polyethylene bags containing oxygen-saturated water; multiple bags with fish are then densely packed into insulated boxes or shipping containers (Cole et al. 1999).

In early 2010, a USGS biologist residing in Guam observed a street vendor selling live freshwater turtles, presumably intended as pets rather than for food (E. Wostl, U.S. Geological Survey, oral commun., 2010). We presume that the nonindigenous turtles were taken from an established wild population. In fact, freshwater turtles, typically red-eared sliders, are offered for sale by street vendors on a semi-regular basis in at least one village on Guam. How many turtles and the variety of species which are sold is unclear. It is assumed that theses turtles are being harvested locally. This type of unauthorized pet trade increases the risk that the range of already established populations will more rapidly expand with the aid of humans.

The senior author of this report visited a pet shop in Saipan; the owners had converted part of their dwelling to a retail sales shop, plumbed it with aquaria, and were selling a small assortment of tropical freshwater aquarium fish. We are unaware if there are additional pet shops in Micronesia.

We are unaware of any outdoor facilities used for the propagation of aquarium or other ornamental species on Guam or elsewhere in Micronesia. However, there are various types of ornamental ponds and other outdoor holding facilities, some of which may have the potential to allow for escape or dispersal. For instance, some hotels on Guam and Saipan maintain water gardens with live ornamental fish (mostly koi, *Cyprinus carpio*, and milkfish, *Chanos chanos*). The senior author observed swordtails (*Xiphophorus helleri*) in an aquarium in the gift shop of the Etpison Museum in Koror, Palau; when asked about the source of fish, an employee responded that the fish had been brought to the museum by the director, who had maintained (and presumably bred) the fish in a pond on her private property.

Table 29. List of nonindigenous freshwater fishes observed for sale or display during a survey of retail pet stores on Guam, April 2010. [Common names in quotation marks as indicated on store aquaria. Most of the common names are the same as those displayed on the tanks containing the particular fish. Some of the scientific names provided are considered tentative because vouchers were not available for examination, combined with the difficulty in positively identifying live fish]

| Family | Common name | Scientific name |
|---|---|---|
| ? | "peacock ram" | |
| ? | "flying phoenix" | |
| ? | "catfish" | |
| Anostomidae | Leporinus | *Leporinus* sp. |
| Apteronotidae | "ghost knifefish," “ghost fish” | *Apteronotus albifrons* |
| Belontiidae/Helostomatidae | "assorted gouramis" | |
| Callichthyidae | "panda cory" | *Corydoras panda* |
| Characidae | "spotted tetra" | *Copella ? nattereri* |
| Characidae | "rednose tetra" | *Hemigrammus bleheri* |
| Characidae | "glowlight tetra" | *Hemigrammus erythrozonus* |
| Characidae | "rummy nose tetra" | *Hemigrammus rhodostomus* |
| Characidae | "black phantom tetra" | *Hyphessobrycon megalopterus* |
| Characidae | "red tail tetra" | *Hyphessobrycon* sp. (perhaps *colombianus*) |
| Characidae | silver dollar | *Metynnis* sp. |
| Characidae | "congo tetra" | *Phenacogrammus interruptus* |
| Characidae | "cherry tetra" | *Puntius titteya* |
| Characidae | "neon glass tetra" | |
| Characidae | "red tag tetra" | |
| Cichlidae | "agassi bluetail cichlid" | |
| Cichlidae | "red zebra" | *Maylandia or Metriaclina ? estherae* |
| Cichlidae | "green terror" | *Aequidens rivulatus* |
| Cichlidae | "oscar" | *Astronotus* |
| Cichlidae | "frontosa" or "red frontosa" | *Cyphotilapia frontosa* |
| Cichlidae | "blue frontosa" | *Cyphotilapia frontosa* |
| Cichlidae | "blue lumphead cichlid" | *Cyrtocara moori* |
| Cichlidae | severum | *Heros severus* |
| Cichlidae | "golden severum" | *Heros severus* |
| Cichlidae | "parrot cichlid" | *Hoplarchus psittacus* |
| Cichlidae | "flowerhorn" | hybrid |
| Cichlidae | "yellow labidochromis" | *Labidochromis caeruleus* |
| Cichlidae | "zebra cichlid" | *Maylandia (Pseudotropheus) zebra* |
| Cichlidae | angelfish | *Pteryophyllum* sp. |
| Cichlidae | "discus" | *Symphysodon* sp. |
| Cichlidae | "firemouth" | *Thorichthys meeki* |
| Cichlidae | "golden goddess" [flowerhorn?] | |

Table 29. List of nonindigenous freshwater fishes observed for sale or display during a survey of retail pet stores on Guam, April 2010. [Common names in quotation marks as indicated on store aquaria. Most of the common names are the same as those displayed on the tanks containing the particular fish. Some of the scientific names provided are considered tentative because vouchers were not available for examination, combined with the difficulty in positively identifying live fish]

| Family | Common name | Scientific name |
|---|---|---|
| Cichlidae | "jewel cichlid" | |
| Cichlidae | "blue cichlid" | |
| Cichlidae | "white cichlid" | |
| Cichlidae | "yellow cichlid" | |
| Cichlidae | "orange cichlid" | |
| Cobitidae | "pakistani loach" | *Botia lohachata/almorhae* |
| Cobitidae | "weather loach" | *Misgurnus anguillicaudatus* |
| Cyprinidae | "bala shark" | *Balantiocheilos melanopterus* |
| Cyprinidae | "tinfoil barb" | *Barbonymus schwanenfeldii* |
| Cyprinidae | goldfish | *Carassius auratus* |
| Cyprinidae | "shubukin" | *Carassius auratus* |
| Cyprinidae | "pearl scale" | *Carassius auratus* |
| Cyprinidae | "assorted oranda" [goldfish variety?] | *Carassius auratus* |
| Cyprinidae | "black moor" | *Carassius auratus* |
| Cyprinidae | "ryukin" | *Carassius auratus* |
| Cyprinidae | "ranchu" | *Carassius auratus* |
| Cyprinidae | carp/koi | *Cyprinus carpio* |
| Cyprinidae | "koi" | *Cyprinus carpio* |
| Cyprinidae | "pearl danio" | *Danio albolineatus* |
| Cyprinidae | "glowlight danio" | *Danio choprai* |
| Cyprinidae | "zebra danio" | *Danio rerio* |
| Cyprinidae | "danio" | *Danio* sp. |
| Cyprinidae | "red danio" | *Danio* sp. |
| Cyprinidae | "pink danio" | *Danio* sp. |
| Cyprinidae | "rainbow shark" | *Epalzeorhynchos frenatum* |
| Cyprinidae | "flying fox algae eater" | *Epalzeorhynchos kalopterus* |
| Cyprinidae | "buenos aires tetra" | *Hyphessobrycon anisitsi* |
| Cyprinidae | "apollo shark" | *Luciosoma pellegrini/setigerum/spilopleura* |
| Cyprinidae | "silver dollars" | *Metynnis* sp. |
| Cyprinidae | "neon tetra" | *Paracheirodon innesi* |
| Cyprinidae | "tiger barb" | *Puntius anchisporus* |
| Cyprinidae | "assorted tiger barbs" | *Puntius anchisporus* |
| Cyprinidae | "rosy barb" | *Puntius conchonius* |
| Cyprinidae | "red barb" | *Puntius conchonius* |

Table 29. List of nonindigenous freshwater fishes observed for sale or display during a survey of retail pet stores on Guam, April 2010. [Common names in quotation marks as indicated on store aquaria. Most of the common names are the same as those displayed on the tanks containing the particular fish. Some of the scientific names provided are considered tentative because vouchers were not available for examination, combined with the difficulty in positively identifying live fish]

| Family | Common name | Scientific name |
|---|---|---|
| Cyprinidae | "gold barbs" | *Puntius semifasciolatus* |
| Cyprinidae | "cherry barb" | *Puntius titteya* |
| Cyprinidae | "harlequin rasbora" | *Trigonostigma (*formerly *Rasbora) heteromorpha* |
| Cyprinidae | "nine barb" | |
| Helostomatidae | "kissing gourami" | *Helostoma temminckii* |
| Loricariidae | "orange marble pleco" | *Ancistrus* ? sp. |
| Loricariidae | | *Hypostomus* sp. |
| Loricariidae | | *Pterygoplichthys* sp. |
| Monodactylidae | "sea angel" | *Monodactylus* ? *argenteus* |
| Notopteridae | "clown knife" | *Chitala chitala* |
| Osphronemidae | "betta" | *Betta* sp. |
| Osphronemidae | "betta" | *Betta* sp. |
| Osphronemidae | "dwarf gourami," "dwarf gouramy" | *Colisa lalia* |
| Osphronemidae | "paradise fish" | *Macropodus opercularis* |
| Osteoglossidae | "arowana" | *Scleropages formosus* |
| Pangasiidae | "siamese shark" | *Pangasius hypothalamus/sutchi* |
| Poeciliidae | "guppy" | *Poecilia reticulata* |
| Poeciliidae | "molly" | *Poecilia* ? *sphenops* ? |
| Poeciliidae | "swordtail" | *Xiphophorus* ? *hellerii* |
| Poeciliidae | "platy" | *Xiphophorus* ? *maculatus/variatus* |
| Poeciliidae | "platy" | *Xiphophorus maculatus* |
| Tetraodontidae | "green pufferfish" | *Tetraodon fluviatilis* |
| Toxotidae | "archer fish" | *Toxotes* sp. |

### Current Management Practices

Live animals brought to Guam legally must be declared. Individuals arriving in Guam from foreign ports must complete a U.S. Customs and Border Protection (CBP) Declaration Form
6059B, which is handed to the CBP inspector upon approaching the CBP area. If a traveler is transporting live animals, the cargo must be indicated on the form, which may result in additional questioning and possible inspection of the traveler’s articles. Because airline passengers are not permitted to transport substantial volumes of liquids in carry-on luggage, there is a low probability that travelers typically carry live fish or other aquatic animals. Regulations pertaining to checked luggage and other transport or shipment of live aquatic animals apparently vary among the different passenger and freight air carriers.

The U.S. Department of the Interior, Law Enforcement Division, USFWS, has responsibility pertaining to the importation of reptiles, fish, and endangered species. A license is required for commercial imports or exports of fish and wildlife and/or their parts and products into or out of the United States (USFWS 2010) and importers are also required to file a Declaration for Importation or Exportation of Fish or Wildlife (Form 3-177) at an authorized port of entry to receive clearance before U.S. Customs releases the shipment. Live aquatic animals and other wildlife are monitored through a system of national ports designated and managed by the USFWS Office of Law Enforcement, USCS, and the USDA.

The Port of Guam in Agana is one of a number of United States ports designated to handle commercial traffic of live wildlife (see: *http://www.fws.gov/pacific/lawenforcement/portag.html*). The Guam office is overseen by the Pacific Islands Resident Agent in Charge subdistrict office which includes Hawaii, the CNMI, the territories of Guam and American Samoa, and other central and western Pacific islands subject to the jurisdiction of the United States (see: *http://www.fws.gov/pacific/lawenforcement/RAC%20Honolulu.html*).

The most detailed records pertaining to imports of live aquatic animals are those in the USFWS Law and Enforcement Management Information System (LEMIS) (Smith et al. 2008). The USFWS compiles much of the information from Customs shipment declaration forms (Form 3-177), which are completed for each shipment that arrives or exits a given U.S. port of entry (Chapman et al. 1997; Adams et al. 2001). LEMIS shipment records include information on number of animals (or their weight) per container, scientific name, intended purpose (e.g., commercial, personal), source (e.g., captive bred, wild caught), and country of origin; import records are discarded every six years (Smith et al. 2008). Some data do not distinguish freshwater from marine species, and not all import declaration forms indicate source. Moreover, country of origin is not always known with certainty since transshipments are common (Chapman et al. 1997; Adams et al. 2001). According to Smith et al. (2008), inadequate record keeping at ports makes it difficult to fully assess the diversity of live fishes imported, thereby hindering risk analysis and prevention programs.

Augmenting regulations and requirements of the USFWS, DAWR applies its white list of aquatic species—mostly aquarium fishes—that can be legally imported live into Guam. Importation of aquatic animals not present on the white list is prohibited; requests for exemptions to the list are reviewed on a case-by-case basis. The most recent version of the white list (provided to us in early 2010 by Brent Tibbatts, DAWR) includes a mix of 448 different genera, species, and hybrid freshwater fishes, saltwater fishes, and aquatic invertebrates. Since 1981, DAWR has not issued any permits allowing the importation of any turtle species into Guam for personal or commercial use (Leberer 2003). All reptiles and amphibians are currently prohibited from importation into Guam. Only saltwater fish species native to Guam can be legally imported.

### Prognosis

The primary mechanisms by which future introductions and spread of nonindigenous aquatic species through the aquarium pet and ornamental species trade are likely to occur include: (1) unauthorized imports and subsequent (intentional) release to the environment; (2) organisms legally imported, purchased by consumers, and subsequent (intentional) release to the environment; and (3) organisms legally or illegally imported and accidentally escaping from holding facilities into the environment:

(1) It is anticipated that an increase in the human population on Guam will result in an increase in the number of freshwater aquarium fishes and other aquatic pets carried or sent to Guam by private citizens outside of the normal retail trade vector. Thus, there will be increased probability that fish and other aquatic species may be transported and subsequently released through this pathway. Future risk potential for establishment of new species by means of this pathway is ***medium/moderately certain***.

(2) The anticipated increase in human population in Guam is also expected to result in increased consumer demand, which will likely increase the volume of legal imports, sales, and ownership of freshwater aquarium fishes and other aquatic pets. This increases propagule pressure by increasing the likelihood of unwanted pets being released into natural waters. It is unknown if increased demand will result in the opening of any additional retail pet stores in Guam. Future risk potential for establishment of new species and/or spread of species currently established by means of this pathway is ***medium-to-high/reasonably certain***.

(3) Given that at present there is little indication that ornamental species are commonly held in outdoor facilities on Guam and elsewhere in Micronesia, future risk potential for establishment of new species and/or spread of species by escapement by means of this pathway is ***low-to-medium/reasonably uncertain***.

## Freshwater Aquaculture Industry

Freshwater aquaculture is the farming of freshwater species in ponds and tanks for subsequent sale as food, either live, fresh, or frozen, for human consumption (in our assessment, it excludes aquaculture associated with the aquarium pet trade and other ornamental species). The freshwater aquaculture industry is a pathway that includes a variety of aquatic animals (principally finfish and shellfish). Included are eggs and fry of various fishes that are imported and subsequently reared to marketable size at aquaculture facilities. In addition, aquaculture facilities commonly hold fishes and other aquatic animals in captivity to replenish their stocks. Personnel at some facilities, usually intending to improve the marketability of their stock, experiment in an effort to produce new strains and hybrids. The mechanism by which nonindigenous aquatic species become introduced into natural water bodies by this pathway typically involves escapement from captive holding facilities, often through accidental, unintended, or natural events (e.g., failure of containment structures, hydrologic alterations, floods, tropical storms). In some Asian countries, freshwater fishes are raised in cages placed in open lakes and rivers, but we are unaware of this practice in freshwater habitats in Guam or other parts of Micronesia. Worldwide, large numbers of commercially important species, both freshwater and marine, have been introduced, established, and spread in association with the food aquaculture sector.

### Present Condition

Aquaculture has long been an active and viable commercial enterprise in Micronesia and elsewhere in Oceania (Fitzgerald and Nelson 1979; FitzGerald 1982; Nelson 1988, 1989b), and continues to flourish (Prasad 2003; NMC-CREES 2011). A substantial amount of food-based aquaculture in the region is of marine species, more strictly referred to as mariculture. Common marine seafood organisms that are cultivated include giant clam, trochus, milkfish, and sea cucumber. The Secretariat of the Pacific Community (SPC) promotes and coordinates much of the aquaculture activities throughout the western Pacific (*http://www.spc.int/aquaculture/*). The SPC headquarters are in Noumea, New Caledonia, with regional offices in the Fiji Islands, FSM (Pohnpei), Papua New Guinea, Solomon Islands, and Vanuatu. Increased interest in mariculture of marine species for the ornamental trade is expected as demand grows (e.g., live corals and other invertebrates, reef fishes).

Within Micronesia, freshwater aquaculture is most highly developed on Guam and in the CNMI. Aquaculture facilities and personnel associated with the University of Guam (UOG) and Northern Marianas College (NMC) support the industry through basic and applied research and extension service. The Guam Aquaculture Development and Training Center (GADTC) of the Western Pacific Tropical Research Center, also known as the Fadian Hatchery, is the largest and oldest aquaculture center in the western Pacific (*http://www.wptrc.org/section.asp?secID=7*). Originally built as a private facility to supply aquaculture products to Asia, the GADTC was transferred to the Government of Guam in 1986 and subsequently to the University of Guam in 2001. The hatchery is located on five acres in the east-central side of Guam and is equipped with indoor laboratories, office buildings and living quarters, ponds and raceways, and sources of sea water and fresh water. A recent effort to organize a Guam aquaculture development working group as a means to facilitate interactions between government agencies and commercial producers was unsuccessful, and instead an improvised process was adopted (CTSA 2010).

Aquaculture in the CNMI is based at the NMC Cooperative Research Extension and Education Service (*http://www.crees.org/sec.asp?secID=1*), which is mandated by public law 15-43 (effective 2007) to be the lead authority for aquaculture development in the CNMI. As part of that legislative directive, the NMC-CREES recently produced an aquaculture development plan based on extensive input from stakeholders throughout the region (NMC-CREES 2011). The NMC-CREES facilities currently include an inland hatchery composed of an assortment of recirculating systems equipped with both fresh and salt water. This facility is used for producing tilapia seedstock for distribution, and for commercial-scale grow-out trials of a variety of species. There are plans to build an additional hatchery. The location for that hatchery has yet to be finalized, but priority factors that are under consideration include (1) access to both fresh and salt water; (2) isolation of the hatchery for biosecurity and security against human intrusion, and; (3) ease of distribution of seed stock to other islands (NMC-CREES 2011).

Most of the current aquaculture production on Guam and in the CNMI involves tilapia (mainly Mozambique tilapia (*Oreochromis mossambicus*), Nile tilapia (*O. niloticus*), and hybrids) and penaeid shrimp (mostly two marine species, the Pacific white shrimp (*Litopenaeus vannamei*) and black tiger prawn (*Penaeus monodon*)). Government-sponsored aquaculture facilities typically conduct research and produce seedstock for distribution to private fish farms, where fish are then raised and eventually distributed to retail food markets.

There is evidence that tilapia fry were imported to Guam from Taiwan as *O. aureus* x *niloticus* hybrids, and permits may have been issued to import genetically pure *O. aureus* (CTSA 2010), but we were unable to independently confirm this. Historically, a number of species were investigated for their aquaculture potential (FitzGerald 1982), and there is also growing interest in experimenting with and utilizing additional species, including native species (M. Ogo and R. Manglona, oral commun., 2010). A list of commodity species for research and production at the NMC-CREES has been prioritized (Table 30). Diseases pose serious problems in aquaculture in general, including the Pacific region, especially with shrimp. The GADTC has been a leader in research to understand and develop guidelines for managing aquaculture-related disease problems (J.W. Brown, oral commun., 2010).

Both facilities at UOG and NMC follow careful biosecurity protocols and staff members are conscientious of the risks involved in holding and culturing nonindigenous species in the vicinity of natural waters. At the GADTC research facility, for instance, all circulating water passes through a filtration system and is eventually dispensed onto dry volcanic rock and then channeled directly to the sea.

The CNMI aquaculture development plan specifically addresses biosecurity issues (Table 31). There is no evidence, to the best of our knowledge, that there have been any recent breaches or escapes from these facilities. The giant river prawn (*Macrobrachium* cf. *rosenbergii*), a taxon of interest in the past, escaped accidentally and may have also been intentionally released into natural waters on Guam. However, this species apparently failed to become established (Eldredge 2000), perhaps from being outcompeted by the native *M. lars* (J.W. Brown, oral commun., 2010). It is unclear to us whether *M. rosenbergii* escaped from government-managed or private aquaculture facilities, or both.

We are unaware of other major freshwater aquaculture facilities throughout the rest of Micronesia. However, mariculture is a growing economic enterprise in Palau and to a lesser extent in the FSM (Prasad 2003; Sakuma and Ueranant 2007; Lindsay 2008). The mariculture industry in Palau and the FSM involves production of species for food (e.g., giant clam, trochus, crab, grouper, rabbitfish, and milkfish), ornamental trade (e.g., live corals), and baitfish (e.g., milkfish for recreational and commercial tuna fishing). The best developed facility in those regions is the Palau Mariculture Demonstration Center (PMDC) on Malakal, originally established in the 1970s as the Micronesian Mariculture Demonstration Center (MMDC). The PMDC is the largest clam factory in the world and mass produces several species of giant clams that are supplied locally and also to many other island nations in the Pacific region, marketed for food, aquaculture, the aquarium trade, and for natural stock replenishment. There was a limited attempt to mass produce freshwater giant prawns (*Macrobrachium* cf. *rosenbergii*) at the PMDC (*http://www.spc.int/aquaculture/index.php?option=com_countries&view=country&id=14*).

Table 30. Priority list of species/groups in production or of interest for aquaculture by the Northern Marianas College Cooperative Research Extension and Education Service (NMC-CREES 2011).

| High Priority | Medium priority | Low priority | Emerging |
|---|---|---|---|
| Tilapia | Marine finfish | Sea cucumbers/sea urchins | Coconut crabs |
| Marine shrimp | Freshwater crustaceans (e.g., *Macrobrachium* cf. *rosenbergii, Procambarus clarkii*) | Corals | Trochus (*Trochus* spp.) |
| | Giant clams (*Tridacna derasa*) | Marine ornamental fish | Sponges |
| | Milkfish (*Chanos chanos*) | Freshwater ornamental fish | Turban shells (*Turbo* spp.) |
| | | Mangrove crabs (*Scylla serrata*) | |

Table 31. Strategies identified to overcome biosecurity challenges for aquaculture in the Commonwealth of the Northern Mariana Islands (NMC-CREES 2011).

| **Objective** | ActionStrategies | Measures |
|---|---|---|
| Minimize risk of disease import | • Laws and regulations reducing potentially harmful imports such as fresh or frozen shrimp.<br>• Increase public awarenenss of biosecurity issues through media such as posters or TV ads.<br>• Establish a quarantine facility.<br>• Improve disease diagnostic and observation capacity. | Biosecurity threats to aquaculture from imported products are eliminated within five years. |
| Minimize risk of harmful invasive species | • Risk assessment of any exotic species importation into CNMI.<br>• Publish and publicize a list of potentially invasive species for CNMI. | Biosecurity threats to aquaculture from potentially invasive species are eliminated within five years. |

### Current Management Practices

As a territory of the United States, Guam is subject to Federal regulations that restrict the importation of certain live aquatic animals intended for aquaculture food production. For example, under the injurious wildlife provisions of the Lacey Act (P.L. 97-79 as amended), the USFWS prohibits the importation and interstate transport of certain injurious terrestrial and aquatic animals, including various species of mammals, birds, fish, amphibians, reptiles, mollusks, and crustaceans. All or most fish species and other taxa currently listed as prohibited under the Lacey Act are associated with the aquaculture industry or the live food industry and includes members of the families Salmonidae (salmon), Clariidae (walking catfishes), Channidae (snakeheads), and four Asian carp species and their hybrids: the largescale silver, silver, bighead, and black carp (Table 32).

Although government programs that support and promote finfish and shellfish aquaculture in Micronesia are generally proactive in implementing established biosecurity protocols, it is less clear how engaged the commercial and private sector is in doing so. Consequently, there are known cases of nonindigenous species becoming established or being spread into natural waters through this pathway. For instance, the chevron snakehead (*Channa striata*) population now established in the Ajayan River in southern Guam is thought to have resulted from the escape of fish from a local fish farm. A number of other nonindigenous fishes and other freshwater animals (e.g., walking catfish, *Clarias* spp., and turtles) were previously imported for use in aquaculture, and are established or reported in the wild. Similar to snakeheads, the source of some or all of these wild populations is possibly due to escapes or releases from aquaculture facilities.

Table 32. Aquatic species listed under the injurious wildlife provisions of the U.S. Lacey Act (*http://www.fws.gov/fisheries/ans/ANSInjurious.cfm*).

| Scientific Name | Common Name |
|---|---|
| Family Salmonidae | salmon[a] |
| Family Clariidae | walking catfish (about 13 genera; ~100 species) |
| Genera *Channa* and *Parachanna* | snakeheads (2 genera; 28 species) |
| *Hypophthalmichthys harmandi* | largescale silver carp (and hybrids) |
| *Hypophthalmichthys molitrix* | silver carp (and hybrids) |
| *Hypophthalmichthys nobilis* | bighead carp (and hybrids) |
| *Mylopharyngodon piceus* | black carp (and hybrids) |
| Genus *Eriocheir* | mitten crabs (three species) |
| Genus *Dreissena polymorpha* | zebra mussel |

[a] Except those accompanied by proper health certification

### Prognosis

It is anticipated that any increase in the human population in Guam will also result in increased demand for food animals produced through aquaculture. It is possible that such demand will also increase the likelihood of development of additional aquaculture facilities, as well as species of interest for aquaculture. Future risk potential for establishment of new species as well as the spread of already established species by means of this pathway is ***medium/moderately certain***.

## Live Food Industry

This pathway includes freshwater fishes or other aquatic animals that are imported live into Guam and other Micronesian islands to be sold as food, as well as freshwater fishes or other aquatic animals that are raised in aquaculture facilities on the islands and distributed live to local stores or markets where they are sold as food. The mechanism by which animals are introduced into natural water bodies by means of this pathway is typically through intentional release or unauthorized release with the intent of establishing populations for subsistence harvesting.

### Present Condition

Except for some live marine animals (e.g., lobsters, crabs, clams), most aquatic animals imported to Guam for human consumption arrive dead as chilled, frozen, dried, or preserved products (Christy et al. 2007b). In contrast, some tilapia that are raised on aquaculture farms in Guam are distributed live to markets on the island where they are sold as food. During our visit to Guam in 2010, we visited at least three stores that were selling small-, medium- and large-sized Nile tilapia (*Oreochromis niloticus*), including both wild and red-color morphs, as well as live shrimp for consumption. Some stores and the farmer's market in Dededo also had live walking catfish for sale. Live animals, presumably supplied entirely by aquaculture facilities, were held in indoor tanks within each store. Based on our observations, consumers are allowed, if desired, to carry fish away live, although it is likely that most purchasers have vendors supply fresh fish or shellfish on ice, either whole or cleaned. It is unknown how many localized populations of popular food species may have been introduced into natural water bodies by means of this pathway.

It is likely that tilapia were introduced to Palau and the FSM with the intent to be stocked locally, possibly illegally and presumably for food. Tilapia (provisionally identified as *O. mossambicus*) were first detected in Palau in 2003, and the Bureau of Agriculture promptly responded with a concerted effort to eradicate fish from four sites using rotenone (Nico and Walsh 2011). However, fish persisted at one site as of 2010, and we were informed that management authorities planned to continue efforts to eradicate fish from this site. Recently, in contrast to previous actions, a legislative bill was under consideration in Palau that was intended to promote tilapia farming in the islands. Senate bill 8-173, dated 9 December 2010, proposed the following:

> "Encourage the development of Tilapia fish farms by providing Palauan citizens with training on developing Tilapia fish farms, and providing local Palauan citizens with seedlings to develop Tilapia fish farms; encourage Palauan citizens to raise, breed, consume, and sell Tilapia fish raised on Tilapia fish farms."

This action prompted knowledgeable scientists and other experts to express concern, on behalf of the Secretariat of the Pacific Regional Environment Programme (SPREP), about potential impacts of tilapia introductions to Palau. Recently we were informed that this issue appears to be resolved and there are currently no further plans to promote tilapia farming in Palau (J. Miles, invasive species coordinator for Palau, written commun., 2011).

We are aware of the interdiction of at least one shipment of swamp eels (*Monopterus* sp.) in Saipan that was presumably imported illegally to be used for food (S. McKagan, oral commun., 2010).

### Current Management Practices

Other than prohibitions against possession or sale of certain species, we are unaware of any management practices related to the distribution of live food fish within Guam. It is unknown to us whether retail markets selling live food fish are required to have permits, if food fish must be killed prior to sale, or if there are regulations in place for the handling and distribution of live or fresh animal products. At the market in Dededo we observed vendors selling live fish and shrimp to customers with no apparent sanitary precautions.

### Prognosis

It is anticipated that any increase in human population in Guam will also result in an increase in the numbers of live fish and other freshwater species provided to food markets on the island. Increased consumer demand may also result in more markets distributing live food products. Future risk potential for establishment of new species as well as the spread of already established species by means of this pathway is ***medium-to-high/moderately certain***. Greater risk may be likely depending on the demographic and ethnic composition of the workforce associated with the military buildup on Guam.

## Recreational Freshwater Fishing

This pathway is associated with sport fishing or casual angling and typically involves government stocking as well as illegal or unauthorized stocking of sport and game fishes and the intentional or accidental release of bait fishes or other aquatic animals or invertebrates used as bait. In freshwater systems, bait releases are typically associated with anglers who release any unused, live bait fishes or other aquatic animals used as bait.

### Present Condition

Guam and other areas of Micronesia have been sites where species have been historically stocked by government agencies, in most cases to establish game species (e.g., sport fishes), food species, and/or as biocontrol agents. For instance, various fish species were intentionally stocked in Fena Reservoir after its construction with the intent to establish them for sportfishing purposes (e.g., *Micropterus* spp., *Ictalurus punctatus*; Table 14) (Guam 1964, 1967). The following excerpt from Guam's Department of Agriculture 1969 annual report (Guam 1969) describes the introduction of Neotropical sportfish of the genus *Cichla*, a group commonly known as peacock bass or tucunare:

> "A South American fresh water game fish called Tucunare, introduced into the 175-acre Fena Lake in February 1968, have spawned and appeared to be firmly established in the lake. By November 1968, at least three distinct sizes of Tucunare were seen in the lake and spillway catchment basin. To develop the fresh water game fishing potential of the island, young Tucunare were also transplanted into one of the large stream systems in the south-central part of the island."

However, stocking of *Cichla* in Fena Reservoir may have also been motivated in part to control tilapia (*Oreochromis mossambicus*), a nonindigenous omnivorous fish that was stocked previously in an attempt to control nonindigenous plants (Brock and Takata 1956). Although the source of populations of some poeciliids currently established on Guam and on other islands in Micronesia may have been through the pet trade, there is also evidence that introductions of some of these species occurred through intentional stockings as biocontrol agents for insect pests (Eldredge 2000) or, in the case of *Poecilia reticulata*, to "balance" the aquatic fauna represented by previously stocked species (Brock and Takata 1956).

Fishing with live bait is a common practice throughout the world and the dispersal and introduction of nonindigenous aquatic species have often been attributed to the release or escape of baitfish and other biota from anglers (Ludwig and Leitch 1996; Fuller et al. 1999). The vector usually involves one or more anglers either accidentally or intentionally dumping the contents of a live-bait well into a water body. On some Pacific islands (e.g., Hawaii), tilapia are used as bait, although perhaps more commonly as cut bait rather than used live (Maciolek 1984). However, we are unaware of any nonindigenous freshwater fish species on Guam or elsewhere in Micronesia having become established by this vector.

### Current Management Practices

In the past, intentional stockings were an important pathway by which nonindigenous species became established on Guam and other Micronesian islands. However, some agencies now recognize the adverse effects of previous stockings that resulted in the establishment of injurious or harmful species. It is our impression that DAWR, and presumably other government agencies in Micronesia, currently undergo a thorough vetting process to evaluate the potential risks associated with fishes or other aquatic species that might be under consideration for intentional stocking in either natural or artificial water bodies. Except for aquaculture interests, there appears to be a prevailing attitude to utilize native species intended for consumptive purposes, at least for recreational fishing.

DAWR does not permit the importation of nonindigenous fishes for use as bait fish (B. Tibbatts, oral commun., 2010). DAWR is currently involved in restoration of the Masso reservoir by removing nonindigenous species, restocking with native species, and providing recreational fishing opportunities. Presumably, anglers will be allowed to fish with live bait, but we are unaware if there will be any regulations or policies implemented to govern the use of such animals. Our assumption is that use of live bait for any type of fishing (saltwater or freshwater) is limited to native species.

#### Prognosis

An increase in the human population on Guam will likely result in an increase in the numbers of individuals on the island interested in freshwater fishing, a situation that might lead to the introduction or spread of nonindigenous sport or bait fish or other animals. Given the abundant fishing opportunities for marine species, relatively limited freshwater sportfishing pressure, and regulations prohibiting importation of freshwater bait species (at least on Guam), there is relatively low probability that this pathway will lead to additional introductions of nonindigenous freshwater fishes in Micronesia for the foreseeable future. DAWR promotes use of native species for recreational angling purposes. Although the possibility exists of people moving freshwater game and/or bait species from one water body to another, the overall current low interest in angling in inland water bodies on Guam suggests that this situation is not likely to change substantially in association with the planned military buildup. Future risk potential for establishment of new species as well as the spread of already established species by means of this pathway is expected to be ***low/reasonably uncertain***.

### Ballast Water and Hull Fouling

#### Present Condition

Transport and release of organisms by means of this pathway is a widespread problem and has led to the establishment of numerous invasive and injurious aquatic species worldwide. This pathway has been cited as the leading cause of introductions of nonindigenous species to navigable coastal waters and inland waterways, and a few natural water bodies such as the Laurentian Great Lakes (Ricciardi and MacIsaac 2000; Fofonoff et al. 2003; Ruiz and Carlton 2003; Drake and Lodge 2004; Drake et al. 2005). Consequently, many practices and policies have been proposed and/or adopted to detect, monitor, and mitigate for translocations of organisms by means of this pathway and associated vectors (Wasson et al. 2002; Drake and Lodge 2004; Fernandez 2008; Hulme et al. 2008; Buck 2009; GWADF 2009). Ballast water and hull fouling differ as vectors in that the first usually involves benthic or free-swimming organisms whereas the second typically involves sessile or attached organisms.

We are unaware of any confirmed cases of established nonindigenous freshwater or diadromous species in Micronesia transported by means of this pathway. Two brackish-water species used in the quantitative risk analysis for this study, the fang-toothed blenny (*Omobranchus ferox*) and the mangrove goby (*Mugiligobius cavifrons*), were assumed to have been introduced to Hawaii by means of ballast water (Englund 2002).

#### Current Management Practices

Current procedures and policies of either the DoD or the commercial and private shipping sectors was not reviewed to determine existing practices or policies intended to prevent or minimize introductions or spread of nonindigenous species by means of this pathway.

#### Prognosis

The volume and network of maritime traffic in and around Micronesia is likely to result in this pathway providing a much greater likelihood for nonindigenous marine organisms than freshwater ones. Future risk potential for establishment of new species as well as the spread of already established species in freshwater habitats of Micronesia by means of this pathway is expected to be ***low/reasonably uncertain***.

### Biological Control

#### Present Condition

Several freshwater fish species present on Pacific islands were introduced for the purpose of biological control (Maciolek 1984). The introduction of peacock cichlid (*Cichla* sp.) to Guam was not only for sportfishing purposes, but also to control feral tilapia (see *Recreational Freshwater Fishing—Present Condition*) (Nelson 1988). The mosquitofish (*Gambusia* sp.) and sailfin molly (*Poecilia latipinna*) were introduced into Hawaii for the biological control of mosquitoes (Van Dine 1907; Yamamoto and Tagawa 2000). It is likely that some poeciliids and certain other small nonindigenous fishes were also stocked on other Pacific islands in the past with the intention of using them to control insect pests. The cane toad *Rhinella marina* was intentionally introduced to various Pacific islands as a biological control agent. For example, it was introduced to the Micronesian island of Pohnpei (in FSM) by occupying Japanese forces during the Second World War to control mosquitoes and grasshoppers and to Fiji in the early 1930s to control beetle (coleopteran) pests of agriculture (Lever 2003). In Guam, the cane toad was first introduced to Agaña Spring in 1937 for insect and slug control (Eldredge 1994, 2000).

#### Current Management Practices

DAWR serves as the main agency to permit the importation of nonindigenous fishes or other aquatic animals for use in biological control. This would likely require careful review and vetting of any plans for such use of nonindigenous species and consideration of possible consequences.

#### Prognosis

We are unaware of any current activities or plans involving introductions of nonindigenous aquatic animals for the purpose of biological control agents. Thus, future risk potential for establishment of any new species by means of this pathway is considered to be ***low/very uncertain***.

## Research

### Present Condition

We are unaware of any past or current activities involving the introduction of nonindigenous aquatic vertebrates or macroinvertebrates to Pacific islands for the explicit purpose of conducting scientific research, other than those species of interest for aquaculture.

### Current Management Practices

DAWR serves as the main agency that issues permits for the importation of nonindigenous fishes or other aquatic animals for use in scientific research. This would likely require careful review and vetting of any plans for such use of nonindigenous species and consideration of possible consequences.

### Prognosis

Future risk potential for establishment and/or spread of nonindigenous species by means of this pathway is ***unknown***.

## Natural Dispersal from Neighboring Waters

This pathway involves the natural dispersal or spread of nonindigenous freshwater aquatic animals. Within freshwater bodies of Pacific islands, this includes natural movement from one island to another, and within a single island, from a drainage where the species is established to an adjacent drainage where it previously did not occur.

### Present Condition

We are unaware of any evidence to indicate that nonindigenous freshwater animals have naturally dispersed to Guam from neighboring islands. However, it is likely that some nonindigenous aquatic animals introduced into one or a few drainages subsequently dispersed naturally into adjacent drainages, as evidenced by their current distribution. For example, the widespread presence of tilapia among Guam drainages suggests that they may have naturally dispersed as well as been intentionally stocked. Peacock cichlids introduced to Fena Reservoir reportedly dispersed to streams downstream of the reservoir (B. Tibbatts and F. Camacho, oral commun., 2010).

### Current Management Practices

We are unaware of any specific management practices on Guam or other Micronesian islands currently aimed at preventing the natural dispersal of nonindigenous aquatic animals.

### Prognosis

Future risk potential for dispersal of nonindigenous species, both those already established on Guam, and/or other Micronesian islands, as well as those with significant probability of becoming established in the future, is ***medium/moderately certain***. This pathway can be affected by different factors, some of which may act in synergy. For example, episodic natural events such as floods or typhoons can create physical conditions that favor dispersal for some species. Moreover, the physiological tolerances of many species may predispose them with the ability to move through habitats (e.g., brackish or full-strength sea water) that would preclude other less-tolerant species.

## Detection

The chance of eradicating a new introduced species decreases the longer one remains undetected (McNeely et al. 2001; Wittenberg and Cock 2001). Early detection of new introductions of nonindigenous fish species will require increasing public awareness plus surveys to monitor sites. Although surveys can and should be used to detect new introductions, the public should be engaged because the sheer size of the human population on Guam greatly increases the likelihood of early detections. The population of Guam was projected as 180,692 in 2010 (Guam Bureau of Statistics and Plans 2009, p. 290). The key is educating the public to recognize new invasive species.

Methods to increase public awareness are described in greater detail below, and emphasize possible use of posters and other media to illustrate native freshwater species in Guam, which may help the public to recognize nonindigenous species by default. In effect, if a member of the public buys or finds a freshwater fish in Guam and that fish is not recognized as being native, then it should not be released. Any fish (or other aquatic species) collected in the wild that is not recognized as native, or not known to be an established nonindigenous species, should be promptly reported to DAWR. Similar posters and other media products that illustrate native and nonindigenous species could be created for other taxonomic groups, such as turtles, frogs, snails, and crustaceans. Reporting could be enhanced by a telephone or text messaging hotline (such as is currently used by DAWR and publicized for reporting occurrence of coqui frogs), and by an online reporting form.

Any specimens of newly detected or introduced species should be preserved as vouchers and added to the museum collection at the University of Guam or another appropriate institution, where specimens could be examined by taxonomic experts to confirm identification. Local newspapers should be encouraged to report any new introductions, together with photographs to document new species on the island, and local biologists are encouraged to publish information about any such specimens in the peer-reviewed literature. The University of Guam publishes the scientific journal *Micronesica* that focuses on the natural sciences and is an appropriate outlet for the publication of new reports of the occurrence, establishment, or spread of introduced species.

### Documenting Imports: Propagule Pressure

To thoroughly understand the potential risks to Micronesia of invasive species originating by means of the pet trade and other pathways requires that the types and numbers of each species imported into Guam and other islands be regularly documented. Currently this information is only partially available. Having this information available would allow for better estimation of propagule pressure (Kolar and Lodge 2001; Lockwood et al. 2005; Colautti et al. 2006; Duggan et al. 2006; Conover et al. 2007; Gertzen et al. 2008). Some information regarding species imported into Guam is recorded by USFWS personnel on Guam (animals from foreign sources) and some information is maintained by DAWR personnel (animals from domestic sources); we were unable to locate or obtain either of these sources of information. The LEMIS data for Guam have been obtained from the USFWS. However, that database generally does not identify aquarium fish to species. In particular, many shipments of fish generally are lumped into a category termed “tropical fish.” The estimated number of freshwater “tropical fish” imported into Guam over the 2007-2009 period totaled 149,650 (67,213 fish in 2007, 60,263 in 2008, and 22,174 in 2009). These numbers only represent fish imported into Guam from foreign sources, not those shipped from Hawaii or the mainland United States. Tracking of imports could be improved if foreign exporters were to list the types and numbers of each species of fish in each shipment arriving in Guam, and if such information were to be recorded by border agents and retained in an electronic database. Additionally, tracking could be further improved if the types and number of each species imported into Guam from domestic sources also were monitored, recorded, and available in an electronic database.

Border agents and wildlife inspectors likely cannot be trained to identify all aquarium animals and plants that are or potentially can be imported into Guam. However, agents are encouraged to receive sufficient training to identify most of the approximately 265 freshwater fish species or species groups and 45 species of aquatic invertebrates (most of which are marine) on the island’s white list (see below), a list of permitted, nonindigenous species that are putatively safe to import insofar as not to pose serious threats of becoming invasive.

Currently the wildlife inspector on Guam apparently inspects about 30% of shipments brought to his attention. Perhaps this percentage could be increased by hiring an additional wildlife inspector or by requiring that live fish be held in quarantine for a brief period to provide inspectors more time to examine each shipment. Photographic documentation of containers and contents might speed the process. Any quarantine would likely increase costs for the government and the private sector. In a quarantine system some fish would need to be housed and fed while in quarantine, and a few of these animals might die from stress or other factors. However, such costs might be offset by preventing the importation of potentially invasive species that otherwise would not have been stopped. Also, diseased fish in quarantine might be identified and any pathogens prevented from spreading to wild populations.

### Documenting Imports: Detecting Imports

Radiograph machines at A.B. Won Pat International Airport, the commercial airport in Guam, may be inadequate to thoroughly screen materials arriving by air; at the onset of this study, equipment was in disrepair as well as insufficient to pass large items (USDA-APHIS 2009). This indicates that contraband materials could enter the island relatively easily. Trained security dogs are used for luggage inspection at Guam’s airport, but we presume that dogs are not trained or are incapable of detecting live aquatic animals. Detection could be improved by repair or replacement of radiograph equipment and increased screening of commercial shipments arriving by air.

Even with increased inspection of known live-animal shipments to Guam, border agents cannot detect all incoming wildlife. The detection probability of live freshwater fishes and other potential nuisance aquatic species could be estimated by conducting controlled trials in which live fish are imported into Guam in known containers, along known pathways, following a predetermined schedule. In a hypothetical scenario, investigators would record the percentage of such packages and fish detected by agents who are unaware of the trial schedule or package characteristics. This information could then be used to estimate the actual number of fish imported annually into Guam by means of each pathway. This would allow for the identification of porous pathways of introduction that subsequently could receive additional attention by inspectors.

#### Postal Service

By law (U.S. Code Title 39, Section 404[c]) domestic mail in the United States is protected and sealed against inspection except under exigent circumstances such as to protect human life or safety, as authorized for intelligence purposes, or if executed by Federal Search Warrant. The postal inspector in Guam currently does not allow domestic mail to be inspected unless the postal inspector is present, and this individual is frequently unavailable (USDA-APHIS 2009). Approximately 95% of mail arriving in Guam is considered domestic mail. Aquarium fish and other aquatic species can be transported by mail services, with some ordered by means of the Internet. As a result, even if customs inspectors documented every aquarium organism transported as ship or air cargo or transported by passengers, an undetermined and potentially large number of nonindigenous animals could be imported into Guam by means of other pathways, including the postal service and private courier services such as Federal Express or the United Parcel Service. Ideally, all mail entering Guam could be inspected by radiograph to establish probable cause for search warrants for undeclared live-animal packages. However, radiograph equipment at the main U.S. sorting facility in Guam was inoperative at the onset of this study (USDA-APHIS 2009). Moreover, it is unknown to us how much domestic mail is inspected.

Currently, most international mail destined for Guam enters the United States in Hawaii where it can be inspected relatively easily (USDA-APHIS 2009). From that point, such mail is considered domestic U.S. mail and a search warrant is required to inspect it once it reaches Guam. Perhaps in the future postal workers in Guam may have the capability to inspect a larger percentage of such mail than is done by workers in Hawaii.

Australia inspects 100% of international mail using visual inspection, dogs and radiograph machines (Pheloung 2003). As part of New Zealand's integrated biosecurity system, officials inspected 84% of approximately 51 million pieces of international mail within a year ending 30 June 2000; of those, 94,000 items were opened, of which 30.7% contained risk goods (Hayden and Whyte 2003). Increased interdiction of contraband live animals would result if similar measures were implemented for all mail arriving to Guam from both domestic and international sites of origin. Further improvements at intercepting live-animal shipments could be achieved if efforts were expended to better estimate detection probability, and the results used to help design the most efficient system of mail inspection.

Currently, mail that arrives at Andersen Air Force Base is not inspected (USDA-APHIS 2009). As with commercial shipments, increased inspection of military mail arriving in Guam from off the island would improve detection of undeclared live-animal shipments.

### Permitted and Prohibited Species

#### White List Review

A white list (Simberloff 1998) or a clean list (Case Study 2.5 in Wittenberg and Cock 2001) is a list of nonindigenous species that are considered to be non-invasive and safe to import

(McNeely et al. 2001). This concept is considered to be stricter and safer than relying upon a black or "dirty list" list (Wittenberg and Cock 2001) of species that are prohibited from a given region. A white list follows the precautionary principle (Case Study 3.3 in Wittenberg and Cock 2001) of the idea of guilty until proven innocent (Ruesink et al. 1995; McNeely et al. 2001; Wittenberg and Cock 2001); in other words, of evaluating the tradeoffs by considering those species to be permitted as posing less potential invasive risk. Some researchers have proposed a third category, a "gray list," to include taxa provisionally prohibited (or provisionally permitted) pending further information (the three-list approach has been called "white/black/gray" or "green/red/amber") (Jenkins 2005).

DAWR has developed a white list of freshwater and marine plants and animals that are permitted to be legally imported for the aquarium trade, aquaculture, water gardens, and other uses. Species that are not on the white list are prohibited from being legally imported, with limited exceptions (for example, species allowed to be displayed by the commercial aquarium in Tumon). The white list is made available to those businesses that regularly import plants and animals, mainly pet shops and a small number of aquaculture facilities. A preliminary review of the freshwater fish species included on the white list revealed a few discrepancies in currently accepted nomenclature; the white list is included here with revisions to scientific names and the addition of taxonomic authorities and vernacular names commonly used in the aquarium trade (Table 33). A similar review was not completed for the permitted marine fishes, invertebrates (mostly marine), and the small number of allowable freshwater plants (Tables 34-36).

An independent review of DAWR white list may be warranted, including a process to ensure flexibility in omitting or adding species to the list based on recommendations by experts. Some immediate considerations were proposed from our preliminary review of the list and site visits to pet shops in Guam. For instance, we suggested in an earlier (2010) draft of this document that the legal importation of all armored suckermouth catfishes of the genus *Pterygoplichthys* and related species and genera (various taxa of the family Loricariidae) be reconsidered in Guam. Several species in the genus *Pterygoplichthys* are popular in the aquarium trade and are sold widely, and individuals commonly grow to become quite large. Owners of pet fish are more likely to release fish that become too large to house easily (Gertzen et al. 2008), and the suspected repeated release of aquarium specimens of *Pterygoplichthys* has resulted in their widespread establishment in Hawaii, Florida, Texas, Mexico, Southeast Asia, and elsewhere (Nico et al. 2009). Once released, colonies of fish in the genus *Pterygoplichthys* can cause extensive damage to stream banks by their excavation of numerous nesting burrows (Nico et al. 2009). Some populations that have become established out of their native range reach extraordinary densities. We were recently informed that, effective 31 December 2010, DAWR no longer permits the importation of armored catfishes of the family Loricariidae into Guam (B. Tibbatts, written commun., 2011). Another example of a species that likely should be removed from the list is the bighead carp, *Hypophthalmichthys nobilis*, which was recently listed as injurious by the U.S. Fish and Wildlife Service and is now prohibited from transport between U.S. states and any of its territories (USFWS 2011). The white list also contains other species known to be invasive on Pacific islands (including Guam) and elsewhere, including various cichlids and poeciliids. Some species reach relatively large body size and/or are predatory and thus likely to pose threats to native species, others may be suspected or known superior competitors, and for yet others possible ecological or interspecific impacts remain unknown. A regular review of this list, perhaps on a 5-year basis, would allow incorporation of new information as it becomes available to assess the potential risks associated with the importation of permitted fish.

Table 33. Freshwater fishes on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. Taxonomic authorities from the "Catalog of Fishes" (Eschmeyer 2011). Common names from various sources, including Robins et al. (1991), FishBase® (Froese and Pauly 2011), and popular names in the aquarium trade.

| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Polypteridae | *Erpetoichthys calabaricus* | *Erpetoichthys calabaricus* | Smith 1865 | reedfish |
| Polypteridae | *Polypterus* spp. (all) | *Polypterus* spp. (all) | Lacepède 1803 | bichirs (various names) |
| Osteoglossidae | *Osteoglossum bicirrhosum* | *Osteoglossum bicirrhosum* | (Cuvier 1829) | arawana |
| Osteoglossidae | *Osteoglossum ferrerai* | *Osteoglossum ferreirai* | Kanazawa 1966 | black arawana |
| Pantodontidae | *Pantodon buchholtzi* | *Pantodon buchholzi* | Peters 1876 | freshwater butterflyfish |
| Notopteridae | *Chitala* spp. (all) | *Chitala* spp. (all) | Fowler 1934 | Asian knifefishes or featherbacks |
| Notopteridae | *Notopterus* spp. (all) | *Notopterus* spp. (all) | Lacepède 1800 | featherbacks (various names) |
| Notopteridae | *Papyrocranus afer* | *Papyrocranus afer* | (Günther 1868) | reticulate knifefish |
| Notopteridae | *Papyrocranus congoensis* | *Papyrocranus congoensis* | (Nichols & La Monte 1932) | Congo marble knifefish |
| Notopteridae | *Xenomystus nigri* | *Xenomystus nigri* | (Günther 1868) | African knifefish |
| Mormyridae | *Gnathonemus petersi* | *Gnathonemus petersii* | Günther 1862 | elephantnose fish |
| Mormyridae | *Mormyrus kannume* | *Mormyrus kannume* | Forsskål 1775 | elephant-snout fish |
| Gymnarchidae | *Gymnarchus niloticus* | *Gymnarchus niloticus* | Cuvier 1829 | aba |
| Cyprinidae | *Balantiocheilus melanopterus* | *Balantiocheilos melanopterus* | (Bleeker 1851) | bala shark; tricolor sharkminnow |
| Cyprinidae | *Barbodes* spp. (all) | *Barbodes* spp. (all) | Bleeker 1859 | barbs (various names) |
| Cyprinidae | *Barbus* spp. (all) | *Barbus* spp. (all) | Cuvier & Cloquet 1816 | barbs (various names) |
| Cyprinidae | *Boraras* spp. (all) | *Boraras* spp. (all) | Kottelat & Vidthayanon 1993 | rasboras (various names) |
| Cyprinidae | *Capoeta* spp. (all) | *Capoeta* spp. (all) | barbs (various names) | barbs (various names) |
| Cyprinidae | *Carrasius auratus- not from Asia* | *Carassius auratus* | (Linnaeus 1758) | goldfish, koi |
| Cyprinidae | *Chela* spp. (all) | *Chela* spp. (all) | Hamilton 1822 | danionin barbs (various names) |
| Cyprinidae | *Crossocheilus siamensis* | *Crossocheilus oblongus* | Kuhl & van Hasselt 1823 | Siamese flying fox |
| Cyprinidae | *Cyprinus carpio- not from Asia* | *Cyprinus carpio* | Linnaeus 1758 | common carp |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Cyprinidae | *Brachydanio* spp. (all) | *Danio* spp. (all) | Hamilton 1822 | danios (various names) |
| Cyprinidae | *Danio* spp. (all) | *Danio* spp. (all) | Hamilton 1822 | danios |
| Cyprinidae | *Eirmotus octozona* | *Eirmotus octozona* | Schultz 1959 | false eight-banded barb |
| Cyprinidae | *Epalzeorhynchus* spp. (all) | *Epalzeorhynchos* spp. (all) | Bleeker 1855 | sharkminnows (various names) |
| Cyprinidae | *Esomus danricus* | *Esomus danricus* | (Hamilton 1822) | flying barb |
| Cyprinidae | *Aristichthys nobilis* | *Hypophthalmichthys nobilis* | (Richardson 1845) | bighead carp |
| Cyprinidae | *Morulius chrysophekadion* | *Labeo chrysophekadion* | (Bleeker 1850) | black sharkminnow |
| Cyprinidae | *Labeo* spp. (all) | *Labeo* spp. (all) | Cuvier 1816 | barbs, labeos (various names) |
| Cyprinidae | *Luciosoma setigerum* | *Luciosoma setigerum* | (Valenciennes 1842) | Apollo sharkminnow |
| Cyprinidae | *Microrasbora* spp. (all) | *Microrasbora* spp. (all) | Annandale 1918 | dwarf rasboras (various names) |
| Cyprinidae | *Puntius* spp. (all) | *Puntius* spp. (all) | Hamilton 1822 | barbs (various names) |
| Cyprinidae | *Rasbora* spp. (all) | *Rasbora* spp. (all) | Bleeker 1859 | rasboras (various names) |
| Cyprinidae | *Sawbwa resplendens* | *Sawbwa resplendens* | Annandale 1918 | sawbwa barb |
| Cyprinidae | *Tanichthys albonubes* | *Tanichthys albonubes* | Lin 1932 | White Cloud Mountain fish |
| Cobitidae | *Acanthopsis choirorhynchus* | *Acanthopsis choirorhynchus* | (Bleeker 1854) | horeseface loach |
| Cobitidae | *Botia* spp. (all) | *Botia* spp. (all) | Gray 1831 | loaches (various names) |
| Cobitidae | *Cobitis taenia* | *Cobitis taenia* | Linnaeus 1758 | spined loach |
| Cobitidae | *Lepidocephalus guntea* | *Lepidocephalus guntea* | (Hamilton 1822) | guntea loach |
| Cobitidae | *Leptobotia micronoemocheilus* | *Leptobotia microphthalma* | Fu & Ye 1983 | Chinese loach |
| Cobitidae | *Misgurnus fossilis* | *Misgurnus fossilis* | (Linnaeus 1758) | weatherfish |
| Cobitidae | *Acanthophthalmus kuhlii* | *Pangio kuhlii* | (Cuvier & Valenciennes 1846) | coolie loach |
| Cobitidae | *Pangio* spp. (all) | *Pangio* spp. (all) | Blyth 1860 | loaches (various names) |
| Balitoridae | *Gastromyzon* spp. (all) | *Gastromyzon* spp. (all) | Günther 1874 | hillstream loaches (various names) |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Balitoridae | *Homaloptera* spp. (all) | *Homaloptera* spp. (all) | van Hasselt 1823 | loaches (various names) |
| Balitoridae | *Noemacheilus corica* | *Nemacheilus corica* | (Hamilton 1822) | polka dotted loach |
| Balitoridae | *Pseudogastromyzon* spp. (all) | *Pseudogastromyzon* spp. (all) | Nichols 1925 | hillstream loaches (various names) |
| Balitoridae | *Sinogastromyzon wui* | *Sinogastromyzon wui* | Fang 1930 | butterfly hillstream loach, Chinese butterfly loach |
| Gyrinocheilidae | *Gyrinocheilus aymonieri* | *Gyrinocheilus aymonieri* | (Tirant 1883) | Siamese algae eater |
| Distichodontidae | *Distichodus lussoso* | *Distichodus lusosso* | Schilthuis 1891 | longsnout distichodus |
| Distichodontidae | *Distichodus noboli* | *Distichodus noboli* | Boulenger 1899 | ? |
| Distichodontidae | *Distichodus sexfasciatus* | *Distichodus sexfasciatus* | Boulenger 1897 | sixbar distichodus |
| Distichodontidae | *Nannaethiops unitaeniatus* | *Nannaethiops unitaeniatus* | Günther 1872 | oneline tetra |
| Distichodontidae | *Neolebias* spp. (all) | *Neolebias* spp. (all) | Steindachner 1894 | tetras (various names) |
| Alestidae | *Hemigrammopetersius caudalis* | *Alestopetersius caudalis* | (Boulenger 1899) | yellowtail tetra |
| Alestidae | *Arnoldichthys spilopterus* | *Arnoldichthys spilopterus* | (Boulenger 1909) | African red-eyed characin |
| Alestidae | *Bathyaethiops caudomaculatus* | *Bathyaethiops caudomaculatus* | (Pellegrin 1925) | African moon tetra |
| Alestidae | *Bryconaethiops microstoma* | *Bryconaethiops microstoma* | Günther 1873 | ? |
| Alestidae | *Chalceus* spp. (all) | *Chalceus* spp. (all) | Cuvier 1818 | characins (various names) |
| Alestidae | *Ladigesia roloffi* | *Ladigesia roloffi* | Géry 1968 | Sierra Leone dwarf characin |
| Alestidae | *Lepidarchus adonis* | *Lepidarchus adonis* | Roberts 1966 | jellybean tetra, adonis characin |
| Alestidae | *Phenacogrammus interruptus* | *Phenacogrammus interruptus* | (Boulenger 1899) | Congo tetra |
| Hemiodontidae | *Hemiodopsis* spp. (all) | *Hemiodopsis* spp. (all) | Müller 1843 | hemiodus, hemiodine characins |
| Prochilodontidae | *Semaprochilodus* spp. (all) | *Semaprochilodus* spp. (all) | Fowler 1941 | prochilodus (various names), flagtail characins |
| Anostomidae | *Abramites* spp. (all) | *Abramites* spp. (all) | Fowler 1906 | Headstanders |
| Anostomidae | *Anostomus* spp. (all) | *Anostomus* spp. (all) | Scopoli 1777 | Headstanders |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Anostomidae | *Leporinus* spp. (all) | *Leporinus* spp. (all) | Agassiz 1829 | Leporinus characins |
| Chilodontidae | *Chilodus punctatus* | *Chilodus punctatus* | Müller & Troschel 1844 | spotted headstander |
| Lebiasinidae | *Copella* spp. (all) | *Copella* spp. (all) | Myers 1956 | splashing tetras |
| Lebiasinidae | *Nannobrycon* spp. (all) | *Nannostomus* spp. (all) | Günther 1872 | pencilfishes (various names) |
| Lebiasinidae | *Nannostomus* spp. (all) | *Nannostomus* spp. (all) | Günther 1872 | pencilfishes (various names) |
| Lebiasinidae | *Pyrrhulina* spp. (all) | *Pyrrhulina* spp. (all) | | pyrrhulinas (various names) |
| Gasteropelecidae | *Carnegiella* spp. (all) | *Carnegiella* spp. (all) | Eigenmann 1909 | hatchet fishes (various names) |
| Gasteropelecidae | *Gasteropelecus* spp. (all) | *Gasteropelecus* spp. (all) | Scopoli 1777 | hatchet fishes (various names) |
| Gasteropelecidae | *Thoracocharax stellatus* | *Thoracocharax stellatus* | (Kner 1858) | spotfin hatchetfish |
| Characidae | *Aphyocharax* spp. (all) | *Aphyocharax* spp. (all) | Günther 1868 | tetras (various names) |
| Characidae | *Astyanax mexicanus* | *Astyanax mexicanus* | (De Filippi 1853) | Mexican tetra |
| Characidae | *Boehlkea fredcochui* | *Boehlkea fredcochui* | Géry 1966 | blue tetra |
| Characidae | *Cheirodon* spp. (all) | *Cheirodon* spp. (all) | Girard 1855 | tetras (various names) |
| Characidae | *Corynopoma riisei* | *Corynopoma riisei* | Gill 1858 | swordtail characin |
| Characidae | *Ctenobrycon spilurus* | *Ctenobrycon spilurus* | (Valenciennes 1850 in Cuvier & Valenciennes) | silver tetra |
| Characidae | *Gymnocorymbus ternetzi* | *Gymnocorymbus ternetzi* | (Boulenger 1895) | black tetra Characidae |
| | *Hasemania nana* | *Hasemania nana* | (Lütken 1875) | silvertip tetra |
| Characidae | *Hemigrammus* spp. (all) | *Hemigrammus* spp. (all) | Gill 1858 | tetras (various names) |
| Characidae | *Hyphessobrycon* spp. (all) | *Hyphessobrycon* spp. (all) | Durbin 1908 | tetras (various names) |
| Characidae | *Megalamphodus* spp. (all) | *Hyphessobrycon* spp. (all) | Durbin 1908 | tetras (various names) |
| Characidae | *Iguanodectes spilurus* | *Iguanodectes spilurus* | (Günther 1864) | slender tetra |
| Characidae | *Inpaichthys kerri* | *Inpaichthys kerri* | Géry & Junk 1977 | royal tetra |
| Characidae | *Mimagoniates barberi* | *Mimagoniates barberi* | Regan 1907 | croaking tetra |
| Characidae | *Coelurichthys microlepis* | *Mimagoniates microlepis* | (Steindachner 1877) | blue tetra |
| Characidae | *Moenkhausia* spp. (all) | *Moenkhausia* spp. (all) | Eigenmann 1903 | tetras (various names) |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Characidae | *Nematobrycon* spp. (all) | *Nematobrycon* spp. (all) | Eigenmann 1911 | emperor tetra, rainbow tetra |
| Characidae | *Paracheirodon* spp. (all) | *Paracheirodon* spp. (all) | Géry 1960 | neon, cardinal tetras |
| Characidae | *Petitella georgia* | *Petitella georgiae* | Géry & Boutière 1964 | false rummynose tetra |
| Characidae | *Vesicatrus tegatus* | *Phenacogaster tegatus* | (Eigenmann 1911) | ? |
| Characidae | *Prionobrama filigera* | *Prionobrama filigera* | (Cope 1870) | glass bloodfin |
| Characidae | *Pristella maxilaris* | *Pristella maxillaris* | (Ulrey 1894) | X-ray tetra |
| Characidae | *Rachoviscus* spp. (all) | *Rachoviscus* spp. (all) | Myers 1926 | tetras (various names) |
| Characidae | *Roeboides descalvadensis* | *Roeboides descalvadensis* | Fowler 1932 | humpbacked characin |
| Characidae | *Tetragonopterus argenteus* | *Tetragonopterus argenteus* | Cuvier 1816 | stoplight tetra |
| Characidae | *Thayeria* spp. (all) | *Thayeria* spp. (all) | Eigenmann 1908 | penguinfishes (various names) |
| Crenuchidae | *Crenuchus spilurus* | *Crenuchus spilurus* | Günther 1863 | sailfin tetra |
| Serrasalmidae | *Metynnis hypsauchen* | *Metynnis hypsauchen* | (Müller & Troschel 1844) | silver dollar |
| Serrasalmidae | *Metynnis schreitmuelleri* | *Metynnis hypsauchen* | (Müller & Troschel 1844) | silver dollar |
| Serrasalmidae | *Myleus rubripinnis* | *Myleus rubripinnis* | (Müller & Troschel 1844) | redhook myleus |
| Serrasalmidae | *Mylossoma aureum* | *Mylossoma aureum* | (Spix & Agassiz 1829) | golden silverdollar |
| Crenuchidae | *Poecilocharax weitzmani* | *Poecilocharax weitzmani* | Géry 1965 | black morpho tetra |
| Bagridae | *Pelteobagrus ornatus* | *Hyalobagrus ornatus* | (Duncker 1904) | ? |
| Bagridae | *Mystus tengara* | *Mystus tengara* | (Hamilton 1822) | Pyjama catfish, tengara catfish |
| Bagridae | *Mystus vittatus* | *Mystus vittatus* | (Bloch 1794) | striped dwarf catfish |
| Bagridae | *Leiocassis siamensis* | *Pseudomystus siamensis* | (Regan 1913) | Asian bumblebee catfish |
| Bagridae | *Rita rita* | *Rita rita* | (Hamilton 1822) | rita |
| Siluridae | *Ompok sabanus* | *Kryptopterus sabanus* | (Inger & Chin 1959) | ? |
| Siluridae | *Kryptopterus* spp. (all) | *Kryptopterus* spp. (all) | Bleeker 1857 | glass catfishes (various names) |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Schilbeidae | *Parailla longifilis* | *Parailia congica* | Boulenger 1899 | speckled or Congo glass catfish |
| Schilbeidae | *Platyropius siamensis* | *Platytropius siamensis* | (Sauvage 1883) | Siamese schilbeid catfish |
| Pangasiidae | *Pangasius sutchi* | *Pangasianodon hypophthalmus* | (Sauvage 1878) | striped catfish, iridescent shark, swai |
| Pangasiidae | *Pangasius larnaudi* | *Pangasius larnaudii* | Bocourt 1866 | spot pangasius |
| Pangasiidae | *Pangasius polyuranodon* | *Pangasius polyuranodon* | Bleeker 1852 | ? |
| Erethistidae | *Hara jordani* | *Hara jerdoni* | Day 1870 | Asian stone catfish, anchor catfish |
| Chacidae | *Chaca chaca* | *Chaca chaca* | (Hamilton 1822) | squarehead catfish |
| Ariidae | *Bagre bagre* | *Bagre bagre* | (Linnaeus 1766) | Coco sea catfish |
| Ariidae | *Hexanematichthys leptospis* | *Neoarius leptaspis* | (Bleeker 1862) | salmon catfish |
| Mochokidae | *Synodontis* spp. (all) | *Synodontis* spp. (all) | Cuvier 1816 | squeakers (various names) |
| Doradidae | *Agamyxis pectifrons* | *Agamyxis pectinifrons* | (Cope 1870) | spotted raphael (or talking) catfish |
| Doradidae | *Platydoras costatus* | *Platydoras costatus* | (Linnaeus 1758) | Raphael catfish |
| Auchenipteridae | *Asterophysus batrachus* | *Asterophysus batrachus* | Kner 1858 | gulper catfish |
| Auchenipteridae | *Liosomadoras* spp. (all) | *Liosomadoras* spp. (all) | Fowler 1940 | jaguar catfish (*L. oncinus*), false jaguar catfish (*L. morrowi*) |
| Heptapteridae | *Pimelodella imitator* | *Brachyrhamdia imitator* | Myers 1927 | false cory |
| Pimelodidae | *Sciades pictus* | *Leiarius pictus* | (Müller & Troschel 1849) | painted catfish, sailfin pim |
| Pimelodidae | *Pimelodas pictus* | *Pimelodus pictus* | Steindachner 1876 | pictus catfish, spotted pimelodid |
| Pimelodidae | *Sorubim lima* | *Sorubim lima* | (Bloch & Schneider 1801) | duckbill catfish |
| Callichthyidae | *Corydoras* spp. (all) | *Corydoras* spp. (all) | Lacepède 1803 | cory catfishes |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Loricariidae[1] | *Acanthicus adonis* | *Acanthicus adonis* | Isbrücker and Nijssen 1988 | polka dot lyre tail pleco |
| Loricariidae[1] | *Xenocara dolichopterus* | *Ancistrus dolichopterus* | Kner 1854 | bushymouth catfish |
| Loricariidae[1] | *Farlowella acus* | *Farlowella acus* | (Kner 1853) | whiptail catfish |
| Loricariidae[1] | *Glyptopterichthys* spp. (all) | *Glyptoperichthys* spp. (all) | Weber 1991 | plecos (various names) |
| Loricariidae[1] | *Hypancistrus zebra* | *Hypancistrus* spp. (all) | Isbrücker and Nijssen 1991 | plecos (various names) |
| Loricariidae[1] | *Leoporacanthias galaxias* | *Leporacanthicus galaxias* | Isbrücker & Nijssen 1989 | vampire pleco |
| Loricariidae[1] | *Otocinclus* spp. (all) | *Otocinclus* spp. (all) | Cope 1871 | dwarf suckermouth catfishes, otos (various names) |
| Loricariidae[1] | *Peckoltia* spp. (all) | *Peckoltia* spp. (all) | Miranda Ribeiro 1912 | clown plecos, tiger plecos |
| Loricariidae[1] | *Pterygoplichthys gibbiceps* | *Pterygoplichthys gibbiceps* | (Kner 1854) | leopard pleco |
| Loricariidae[1] | *Liposarcus multiradiatus* | *Pterygoplichthys multiradiatus* | (Hancock 1828) | Orinoco sailfin catfish |
| Loricariidae[1] | *Sturisoma panamens* | *Sturisoma panamense* | (Eigenmann & Eigenmann 1889) | royal whiptail, royal twig catfish |
| Sternopygidae | *Eigenmannia virescens* | *Eigenmannia virescens* | (Valenciennes 1836) | glass knifefish |
| Apteronotidae | *Apteronotus albifrons* | *Apteronotus albifrons* | (Linnaeus 1766) | black ghost knifefish |
| Bedotiidae | *Bedotia geayi* | *Bedotia geayi* | Pellegrin 1922 | Madagascar rainbowfish |
| Melanotaenidae | *Glossolepsis* spp. (all) | *Glossolepis* spp. (all) | Weber 1907 | rainbowfishes (various names) |
| Melanotaenidae | *Iratherina werneri* | *Iriatherina werneri* | Meinken 1974 | threadfin rainbowfish |
| Melanotaenidae | *Melanotaenia* spp. (all) | *Melanotaenia* spp. (all) | Gill 1862 | rainbowfishes (various names) |
| Pseudomugilidae | *Poppendetta conniae* | *Pseudomugil connieae* | (Allen 1981) | popondetta blue-eye or popendetta rainbowfish |
| Pseudomugilidae | *Pseudomugil furcatus* | *Pseudomugil furcatus* | Nichols 1955 | forktail rainbowfish |
| Telmatherinidae | *Telmatherina ladigesi* | *Marosatherina ladigesi* | (Ahl 1936) | Celebes rainbowfish |
| Nothobranchiidae | *Aphyosemion* spp. (all) | *Aphyosemion* spp. (all) | Myers 1924 | African lyretails |
| Nothobranchiidae | *Nothobranchius* spp. (all) | *Nothobranchius* spp. (all) | Peters 1868 | nothos (various names) |

Table 33. Freshwater fishes on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. Taxonomic authorities from the "Catalog of Fishes" (Eschmeyer 2011). Common names from various sources, including Robins et al. (1991), FishBase® (Froese and Pauly 2011), and popular names in the aquarium trade.

| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Rivulidae | *Cynolebius* spp. (all) | *Cynolebias* spp. (all) | Steindachner 1876 | neotropical killifishes (various names) |
| Cyprinodontidae | *Jordanella floridae* | *Jordanella floridae* | Goode & Bean 1879 | flagfish |
| Poeciliidae | *Aplocheilichthys* spp. (all) | *Aplocheilichthys* spp. (all) | Bleeker 1863 | lampeyes |
| Poeciliidae | *Lamprichthys tanganicanus* | *Lamprichthys tanganicanus* | (Boulenger 1898) | Tanganyika killifish |
| Poeciliidae | *Poecilia latipinna* | *Poecilia latipinna* | (Lesueur 1821) | sailfin molly |
| Poeciliidae | *Poecilia reticulata* | *Poecilia reticulata* | Peters 1859 | guppy |
| Poeciliidae | *Poecilia sphenops* | *Poecilia sphenops* | | Mexican molly |
| Poeciliidae | *Poecilia velifera* | *Poecilia velifera* | (Regan 1914) | Yucatan molly |
| Poeciliidae | *Xiphophorus helleri* | *Xiphophorus hellerii* | Heckel 1848 | green swordtail |
| Poeciliidae | *Xiphophorus maculatus* | *Xiphophorus maculatus* | (Günther 1866) | southern platyfish |
| Poeciliidae | *Xiphophorus variatus* | *Xiphophorus variatus* | (Meek 1904) | variable platyfish |
| Hemiramphidae | *Dermogenys pusillus* | *Dermogenys pusilla* | Kuhl & van Hasselt 1823 | wrestling or Malayan halfbeak |
| Mastacembelidae | *Macrognathus siamensis* | *Macrognathus siamensis* | (Günther 1861) | peacock eel |
| Mastacembelidae | *Mastacembelus* spp. (all) | *Mastacembelus* spp. (all) | Scopoli 1777 | spinybacks, mastembelid eels (various names) |
| Ambassidae | *Chanda* spp. (all) | *Chanda* spp. (all) | Hamilton 1822 | perchlets (various names) |
| Ambassidae | *Gymnochanda filamentosa* | *Gymnochanda filamentosa* | Fraser-Brunner 1955 | filament or longfin glassfish |
| Datnioididae | *Datnoides microlepis* | *Datnioides microlepis* | Bleeker 1853 | finescale or Siamese tigerfish |
| Toxotidae | *Toxotes jaculator* | *Toxotes jaculatrix* | (Pallas 1767) | banded archerfish |
| Monodactylidae | *Monodactylus argenteus* | *Monodactylus argenteus* | (Linnaeus 1758) | diamond moonfish, silver moony |
| Scatophagidae | *Selenotoca multifasciata* | *Selenotoca multifasciata* | (Richardson 1846) | spotbanded scat |
| Badidae | *Badis badis* | *Badis badis* | (Hamilton 1822) | blue perch |
| Polycentridae | *Monocirrhus polyacanthus* | *Monocirrhus polyacanthus* | Heckel 1840 | Amazon leaffish |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Cichlidae | *Acarichthys heckelli* | *Acarichthys heckelii* | (Müller & Troschel 1849 in Schomburgk) | threadfin acara |
| Cichlidae | *Aequidens* spp. (all) | *Aequidens* spp. (all) | Eigenmann & Bray 1894 | various names |
| Cichlidae | *Altolamprologus* spp. (all) | *Altolamprologus* spp. (all) | Poll 1986 | lamprologine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Archocentrus nigrofasciatus* | *Amatitlania nigrofasciata* | (Günther 1867) | convict cichlid |
| Cichlidae | *Amphilophus citrinellum* | *Amphilophus citrinellus* | (Günther 1864) | Midas cichlid |
| Cichlidae | *Apistogramma* spp. (all) | *Apistogramma* spp. (all) | Regan 1913 | dwarf cichlids |
| Cichlidae | *Astronotus ocellatus* | *Astronotus ocellatus* | (Agassiz 1831) | oscar |
| Cichlidae | *Aulanocara* spp. (all) | *Aulonocara* spp. (all) | Regan 1922 | peacock cichlids |
| Cichlidae | *Chalinochromis* spp. (all) | *Chalinochromis* spp. (all) | Poll 1974 | lamprologine cichlids (various names) |
| Cichlidae | *Mesonauta salvini* | *Cichlasoma salvini* | (Günther 1862) | yellowbelly cichlid |
| Cichlidae | *Nandopsis salvini* | *Cichlasoma salvini* | (Günther 1862) | yellowbelly cichlid |
| Cichlidae | *Cichlasoma* spp. (all) | *Cichlasoma* spp. (all) | Swainson 1839 | neotropical cichlids (various names) |
| Cichlidae | *Cleithracara maronii* | *Cleithracara maronii* | (Steindachner 1881) | keyhole cichlid |
| Cichlidae | *Copadichromis* spp. (all) | *Copadichromis* spp. (all) | Eccles & Trewavas 1989 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Archocentrus sajica* | *Cryptoheros sajica* | (Bussing 1974) | T-bar cichlid |
| Cichlidae | *Cyathopharynx furcifer* | *Cyathopharynx furcifer* | (Boulenger 1898) | featherfin cichlid |
| Cichlidae | *Cyphotilapia frontosa* | *Cyphotilapia frontosa* | (Boulenger 1906) | humphead cichlid |
| Cichlidae | *Cyprochromis leptosoma* | *Cyprichromis leptosoma* | (Boulenger 1898) | "cyp" |
| Cichlidae | *Cyrtocara moori* | *Cyrtocara moorii* | Boulenger 1902 | hump-head |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Cichlidae | *Dicrossus* spp. (all) | *Dicrossus* spp. (all) | Steindachner 1875 | crenicarine dwarf cichlids; chessboard cichlids |
| Cichlidae | *Dimidochromis* spp. (all) | *Dimidiochromis* spp. (all) | Eccles & Trewavas 1989 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Geophagus* spp. (all) | *Geophagus* spp. (all) | Heckel 1840 | eartheaters (various names) |
| Cichlidae | *Gymnogeophagus balzanii* | *Gymnogeophagus balzanii* | (Perugia 1891) | Argentine humphead |
| Cichlidae | *Haplochromis* spp. (all) | *Haplochromis* spp. (all) | Hilgendorf 1888 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Hemichromis bimaculatus* | *Hemichromis bimaculatus* | Gill 1862 | African jewelfish |
| Cichlidae | *Hemichromis lifalli* | *Hemichromis lifalili* | Loiselle 1979 | blood-red jewel cichlid |
| Cichlidae | *Herichthys carpinte* | *Herichthys carpintis* | (Jordan & Snyder 1899) | lowland cichlid |
| Cichlidae | *Herichthys cyanoguttatus* | *Herichthys cyanoguttatus* | Baird & Girard 1854 | Rio Grande cichlid |
| Cichlidae | *Heros appendiculatus* | *Heros efasciatus* | Heckel 1840 | severum |
| Cichlidae | *Heros severus* | *Heros severus* | Heckel 1840 | banded cichlid |
| Cichlidae | *Hypselacara temporalis* | *Hypselecara temporalis* | (Günther 1862) | emerald cichlid |
| Cichlidae | *Theraps nicaraguense* | *Hypsophrys nicaraguense* | (Günther 1864) | moga |
| Cichlidae | *Julidochromis* spp. (all) | *Julidochromis* spp. (all) | Boulenger 1898 | julies (various names) |
| Cichlidae | *Labeotropheus* spp. (all) | *Labeotropheus* spp. (all) | Ahl 1926 | haplochromine (pseudocrenilabrine) cichlids (various names), Mbunas |
| Cichlidae | *Labidochromis caeruleus* | *Labidochromis caeruleus* | Fryer 1956 | blue streak hap |
| Cichlidae | *Laetacara* spp. (all) | *Laetacara* spp. (all) | Kullander 1986 | smiling acaras |
| Cichlidae | *Lamprologus* spp. (all) | *Lamprologus* spp. (all) | Schilthuis 1891 | lamprologine cichlids |
| Cichlidae | *Melanochromis* spp. (all) | *Melanochromis* spp. (all) | Trewavas 1935 | haplochromine (pseudocrenilabrine) cichlids (various names), Mbunas |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Cichlidae | *Mesonauta festivum* | *Mesonauta festivus* | (Heckel 1840) | flag cichlid |
| Cichlidae | *Microgeophagus* spp. (all) | *Mikrogeophagus* spp. (all) | Meulengracht-Madson in Schiötz & Christensen 1968 | ram cichlids (various names) |
| Cichlidae | *Papiliochromis* spp. (all) | *Mikrogeophagus* spp. (all) | Meulengracht-Madson in Schiötz & Christensen 1968 | ram cichlids (various names) |
| Cichlidae | *Nannacara* spp. (all) | *Nannacara* spp. (all) | Regan 1905 | dwarf cichlids (various names) |
| Cichlidae | *Nannochromis* spp. (all) | *Nanochromis* spp. (all) | Pellegrin 1904 | African dwarf cichlids (various names) |
| Cichlidae | *Neolamprologus* spp. (all) | *Neolamprologus* spp. (all) | Colombé & Allgayer 1985 | lamprologine cichlids |
| Cichlidae | *Ophthalmotilapia* spp. (all) | *Ophthalmotilapia* spp. (all) | Pellegrin 1904 | ? |
| Cichlidae | *Oreochromis mossambicus* | *Oreochromis mossambicus* | (Peters 1852) | Mozambique tilapia |
| Cichlidae | *Otopharynx* spp. (all) | *Otopharynx* spp. (all) | Regan 1920 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Herichthys dovii* | *Parachromis dovii* | (Günther 1864) | Guapote |
| Cichlidae | *Paracyprochromis nigripinnis* | *Paracyprichromis nigripinnis* | (Boulenger 1901) | blue neon cichlid |
| Cichlidae | *Pelvicachromis pulcher* | *Pelvicachromis pulcher* | (Boulenger 1901) | rainbow crib |
| Cichlidae | *Placidochromis* spp. (all) | *Placidochromis* spp. (all) | Eccles & Trewavas 1989 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Protomelas* spp. (all) | *Protomelas* spp. (all) | Eccles & Trewavas 1989 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Pseudocrenilabrus* spp. (all) | *Pseudocrenilabrus* spp. (all) | Fowler 1934 | haplochromine (pseudocrenilabrine) cichlids (various names) |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Cichlidae | *Pseudotropheus* spp. (all) | *Pseudotropheus* spp. (all) | Regan 1922 | haplochromine (pseudocrenilabrine) cichlids (various names), Mbunas |
| Cichlidae | *Pterophyllum* spp. (all) | *Pterophyllum* spp. (all) | Heckel 1840 | angelfishes (various names) |
| Cichlidae | *Satanoperca* spp. (all) | *Satanoperca* spp. (all) | Günther 1862 | eartheaters (various names) |
| Cichlidae | *Scianochromis* spp. (all) | *Sciaenochromis* spp. (all) | Eccles & Trewavas 1989 | haplochromine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Symphysodon aquefasciatus* | *Symphysodon aequifasciatus* | Pellegrin 1904 | blue discus |
| Cichlidae | *Symphysodon discus* | *Symphysodon discus* | Heckel 1840 | red discus |
| Cichlidae | *Thorichthys meeki* | *Thorichthys meeki* | Brind 1918 | firemouth cichlid |
| Cichlidae | *Tropheus* spp. (all) | *Tropheus* spp. (all) | Boulenger 1898 | trophs, tropheine (pseudocrenilabrine) cichlids (various names) |
| Cichlidae | *Uaru amphiacanthoides* | *Uara amphiacanthoides* | Heckel 1840 | triangle cichlid, Uara cichlid |
| Cichlidae | *Herichthys maculicauda* | *Vieja maculicauda* | (Regan 1905) | blackbelt cichlid |
| Cichlidae | *Theraps synspilus* | *Vieja synspila* | (Hubbs 1935) | redhead cichlid |
| Cichlidae | | | | unnamed hybrid produced in captivity? |
| Eleotridae | *Mogurnda adspersa* | *Mogurnda adspersa* | (Castelnau 1878) | purple-spotted gudgeon |
| Eleotridae | *Tateurundina ocellicauda* | *Tateurndina ocellicauda* | Nichols 1955 | peacock gudgeon |
| Gobiidae | *Arenigobius bifrenatus* | *Arenigobius bifrenatus* | (Kner 1865) | bridled goby |
| Gobiidae | *Brachygobius* spp. (all) | *Brachygobius* spp. (all) | Bleeker 1874 | bumblebee gobies |
| Gobiidae | *Stigmatogobius sadanundio* | *Stigmatogobius sadanundio* | (Hamilton 1822) | knight goby |
| Anabantidae | *Coius* spp. (all) | *Anabas* spp. (all) | Cloquet 1816 | anabantids; climbing perch or climbing bass (*A. testudineus*) |
| Helostomatidae | *Helostoma temminki* | *Helostoma temminkii* | Cuvier 1829 | kissing gourami |
| Osphronemidae | *Betta* spp. (all) | *Betta* spp. (all) | Bleeker 1850 | bettas (various names) |

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| Family | Name on original list | Current accepted name | Authority | Common name |
|---|---|---|---|---|
| Osphronemidae | *Colisa* spp. (all) | *Colisa* spp. (all) | Bloch & Schneider 1801 | gouramis (various names) |
| Osphronemidae | *Macropodus* spp. (all) | *Macropodus* spp. (all) | Lacepède 1801 | paradise gouramis (various names) |
| Osphronemidae | *Osphronemus goramy* | *Osphronemus goramy* | Lacepède 1801 | giant gourami |
| Osphronemidae | *Sphaerichthys osphremenoides* | *Sphaerichthys osphromenoides* | Canestrini 1860 | chocolate gourami |
| Osphronemidae | *Trichogaster* spp. (all) | *Trichogaster* spp. (all) | Bloch & Schneider 1801 | gouramis (various names) |
| Osphronemidae | *Trichopsis* spp. (all) | *Trichopsis* spp. (all) | Canestrini 1860 | gouramis (various names) |
| Achiridae | *Achirus errans* | *Catathydrium jenynsii* | Miranda Ribeiro 1915 | Brazilian freshwater sole |
| Achiridae | *Trinectes maculatus* | *Trinectes maculatus* | (Bloch & Schneider 1801) | hogchoker |
| Tetraodontidae | *Monotretus travancoricus* | *Carinotetraodon travancoricus* | (Hora & Nair 1941) | Malabar pufferfish |
| Tetraodontidae | *Colomesus* spp. (all) | *Colomesus* spp. (all) | Gill 1884 | South American or banded puffers |
| Tetraodontidae | *Tetraodon biocellatus* | *Tetraodon biocellatus* | Tirant 1885 | eyespot pufferfish, figure-eight puffer |
| Tetraodontidae | *Tetraodon fluviatilis* | *Tetraodon fluviatilis* | Hamilton 1822 | green pufferfish |
| Tetraodontidae | *Tetraodon fahaka* | *Tetraodon lineatus* | Linnaeus 1758 | globe fish |
| Tetraodontidae | *Tetraodon miurus* | *Tetraodon miurus* | Boulenger 1902 | Congo pufferfish |
| Tetraodontidae | *Tetraodon nigroviridis* | *Tetraodon nigroviridis* | Marion de Procé 1822 | spotted green pufferfish |

[1] Species in family no longer permitted for importation, effective 31 December 2010.

Table 34. Marine fishes on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. [UWW, Underwater World, a commercial aquarium in Tumon]

| | | |
|---|---|---|
| *Acanthurus achilles* | *Ctenochaetus strigosus* | *Novaculichthys taeniourus* |
| *Acanthurus olivaceous* | *Diodon holocanthus* | *Ostracion cubicus* |
| *Amblyeleotris fasciata* | *Echenius naucrates* | *Oxycirrhites typus* |
| *Amblyeleotris guttata* | *Echidna nebulosa* | *Paracanthurus hepatus* |
| *Amblyeleotris steinitzi* | *Ecsenius bicolor* | *Paracirrhites arcatus* |
| *Amphiprion clarckii* | *Epinephalis lanceolatus* | *Paracirrhites forsteri* |
| *Amphiprion peredarion* | *Forcipiger flavissimus* | *Paraglyphidodon oxyodon* |
| *Anampses meleagrides* | *Forcipiger longirostris* | *Parapeneus barberinoides* |
| *Antennarius hispidus* | *Genicanthus* spp. (all) | *Parapeneus cyclostomus* |
| *Antennarius striatus* | *Gnathanodon speciosus* | *Phyllopteryx taeniolatus* UWW only-captive bred only |
| *Anthias alleni* | *Gobiodon atrangulatus* | *Platax* spp. (all) |
| *Anthias dispar* | *Gobiodon histrix* | *Plectorhinchus* spp. (all) |
| *Anthias evansi* | *Gomphosus varius* | *Pogonoculius zebra* |
| *Anthias squamapinnis* | *Gorgasia preclara* | *Pogonoperca punctata* |
| *Anthias tuka* | *Halichoeres biocellatus* | *Pomacanthus imperator* |
| *Apogon cyanosoma* | *Halichoeres chrysus* | *Pomacentrus* spp. (all) |
| *Apolemichthys trimaculatus* | *Hemipteronotus taeniourus* | *Promicrops lanceolatus* |
| *Balistoides conspicillum* | *Heniochus acuminatus* | *Pseudanthias* spp. (all) |
| *Bothus mancus* | *Heteroconger hassi* | *Pseudechidna brummeri* |
| *Calloplesiops altivelis* | *Hippocampus abdominalis* UWW only-captive bred only | *Pseudocheilinus hexataenia* |
| *Centropyge* spp. (all) | *Histrio histrio* | *Pseudochromis diadema* |
| *Cephalopholis miniatus* | *Hoplolatilus chlupatyi* | *Pseudochromis paccagnelae* |
| *Cephalopholis sexmaculata* | *Hoplolatilus fourmanoiri* | *Pseudochromis porphyrous* |
| *Cephalopholis urodeta* | *Hoplolatilus starcki* | *Pteeleotris heteropterus* |
| *Cetoscarus bicolor* | *Labroides dimidiatus* | *Pterapogon kauderni* UWW only-captive bred only |
| *Chaetodon benneti* | *Labropsis micronesica* | *Ptereleotris coeruleus* |
| *Chaetodon melannotus* | *Labropsis xanthonota* | *Ptereleotris evides* |
| *Chaetodon meyeri* | *Lactoria cornuta* | *Pygoplites diacanthus* |
| *Chaetodon punctatofasciatus* | *Lutjanus kasmira* | *Rhinecanthus aculeatus* |
| *Chaetodon reticulatus* | *Macolor macularis* | *Rhinobatus hynnicephalus* |
| *Chaetodon rostratus* | *Macropharyngodon meleagris* | *Rhinomuraena quaesita* |
| *Chaetodon trifascialis* | *Malacanthus latovittatus* | *Rhinopias* spp. (UWW only) |
| *Chaetodon unimaculatus* | *Meiacanthus atrodorsalis* | *Salarias fasciatus* |
| *Chaetodon vagabundus* | *Meiacanthus grammistes* | *Salarias irroratus* |
| *Chiloscyllium colax* | *Mirolabrichthys imeldae* | *Sargocentron spiniferum* |
| *Chiloscyllium punctatum* | *Monocentrus japonicus* | *Serranocirrhitus latus* |

Table 34. Marine fishes on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. [UWW, Underwater World, a commercial aquarium in Tumon]

| | | |
|---|---|---|
| *Cirrhitichthys falco* | *Muraena pardalis* | *Solenostomus paradoxus* |
| *Cirrhitichthys oxycephalus* | *Myrichthys colubrinus* | *Spilotichthys pictus* |
| *Coris aygula* | *Myrichthys maculosus* | *Symphorichthys spilurus* |
| *Coris gaimard* | *Nemateleotris decora* | *Taeniura lymma* (UWW only and only males) |
| *Cromileptes altivelis* | *Nemateleotris magnifica* | *Thalassoma lutescens* |
| *Cryptocentrus cyanotaenia* | *Neocirrhites armatus* | *Xyrichthys pavo* |
| *Ctenochaetus marginatus* | *Neoglyphidodon melas* | *Zebrasoma flavescens* |
| *Ctenochaetus strigosus* | | *Zebrasoma veliferum* |

Table 35. Invertebrates on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. [UWW, Underwater World, a commercial aquarium in Tumon]

| | |
|---|---|
| Crabs and shrimp | *Acanthocephala limabat* |
| | *Calappa lophos* |
| | *Camposia retusa* |
| | *Hippolysmata grabhami* |
| | *Hymenocera elegans* |
| | *Hymenocera picta* |
| | *Limulus polyhemus* |
| | *Lybia tessellata* |
| | *Lysmata amboinensis* |
| | *Lysmata debelius* |
| | *Macrochir kaempferi* (UWW only) |
| | *Neopetrolisthes oshimmai* |
| | *Neopetrolisthes maculatus* |
| | *Oncinopus decapoda* |
| | *Rhynchocinetes durbanensis* |
| | *Rhynchocinetes uritai* |
| | *Saron marmoratus* |
| | *Saron rectirostris* |
| | *Stenopus hispidus* |
| | *Thor amboinensis* |
| Anemones and slugs | *Cerianthus ceriantharia* |
| | *Cerianthus filiformis* |
| | *Cryptodendrum adhesivum* |

Table 35. Invertebrates on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation. [UWW, Underwater World, a commercial aquarium in Tumon]

| | |
|---|---|
| | *Cribinopsis crassa* |
| | *Filogranella elatensis* |
| | *Heteractis aurora* |
| | *Heteractis magnifica* |
| | *Heterodactyla hemprichii* |
| | *Hexabranchus sanguinensis* |
| | *Phyllidia varicosa* |
| | *Stichodactyla mertensii* |
| | *Stoichactis haddoni* |
| | *Urticina felina* |
| Starfish and jellyfish | *Aurelia aurita Cassiopea* |
| | *frondosa Certonardoa* |
| | *semiregularis Clypeaster* |
| | *humilis* |
| | *Fronia monilis* |
| | *Linkia laevigata* |
| | *Mastigias papua* |
| | *Olindias formosa* (UWW only) |
| | *Pentaster obtusatus* |
| | *Protoreaster dodosus* |
| | *Phyllorhiza punctata* |
| Other invertebrates | *Sabillastarte indica* |

Table 36. Freshwater plants on the Guam Division of Aquatic and Wildlife Resources white list of species permitted for legal importation.

| |
|---|
| *Anubias* spp. |
| *Cryptocoryne* spp. |
| *Echinodorus* spp. (except for *E. cordifolius*, *E. osiris*, and *E. uruguayensis*) |
| *Aponogeton* spp. |
| *Microsorium pteropus* |
| *Spathiphyllum tasson* |
| *Vesicularia dubyana* |

### Faunistic Surveys and Monitoring

Wittenberg and Cock (2001) describe three types of surveys designed for early detection of new introductions of nonindigenous species: general surveys, site-specific surveys and species-specific surveys. Such surveys must be repeated regularly to be effective.

As a general survey, one possibility is an occupancy survey (MacKenzie et al. 2006) similar to the North American Breeding Bird Survey (Sauer et al. 1994; *http://www.pwrc.usgs.gov/bbs/*), the Swiss Breeding Bird Monitoring Program (Kéry et al. 2005), the Swiss Butterfly Monitoring Program (Kéry et al. 2009), or the U.S. Geological Survey's North American Amphibian Research and Monitoring Initiative (*http://armi.usgs.gov/*). Details of survey design could be established through consultation with appropriate experts. For aquatic surveys of freshwater sites in Guam and elsewhere in Micronesia, sampling could utilize different methods, such as minnow seines, dip nets, passive fish traps, and visual observation (Hankin and Reeves 1988), depending on the knowledge and experience of personnel conducting surveys.

#### *Site-Specific Surveys*

These types of surveys are intended to target areas that have high conservation value (e.g., ecosystem prioritization) or are near high-risk entry points (Wittenberg and Cock 2001; Jenkins et al. 2009). Examples of the latter would include areas near human population centers, aquaculture facilities, and/or ports of entry. DAWR currently has a routine river and wetland survey and monitoring program in place that includes targeted sites as well as new ones; additional aquatic surveys are conducted by University of Guam researchers and the U.S. National Park Service. A review of these sites and consideration of additional sites to target specifically for monitoring potential new introductions requires careful consultation between agency biologists and cooperators. Perhaps 20-50 randomly-selected survey sites could be chosen in or near each area as listed above. Potential sites to be targeted in Guam could include: Apra Harbor, Guam International Airport, Andersen Air Force Base, Agana Swamp (Guam's largest natural freshwater marsh), Fena Reservoir (the main reservoir in Guam), Sasa Bay Wetland (102 hectares of estuarine and freshwater wetland), Atantano Wetland (130 hectares of estuarine and freshwater wetland), the Talofofo River Valley (the largest contiguous water body in Guam), and current and former aquaculture facilities.

#### *Species-Specific Surveys*

In Guam, these surveys would overlap substantially with site-specific surveys, but potentially could target species currently known to be present, such as snakeheads (*Channa* spp.), tilapia (*Oreochromis* spp., hybrids, and *Tilapia zillii*), peacock cichlids (*Cichla* sp.), walking catfish (*Clarias* spp.), as well as other taxa of special concern, such as swamp eels (Synbranchidae). Species-specific surveys might focus more on ponds, current and former aquaculture facilities, Guam's reservoirs, Agana Swamp, golf courses, and river mouths rather than focusing on stream reaches, at least if the aforementioned species were targeted.

#### *Volunteer Surveyors*

Conducting regular surveys likely would require more effort and resources than are currently available to DAWR and other Micronesian agencies. Elsewhere, some large-scale intensive surveys are volunteer-based; use of volunteers to survey for invasive species in Guam could enhance early detection. Such efforts would be further enhanced with sufficient funding to support a survey coordinator and adequate training of volunteers.

A potential pool of volunteers might involve government biologists, military personnel in charge of managing natural resources, park personnel, students at the University of Guam, local naturalists, interested anglers, and high school students. Such volunteer groups could adopt one or more sites to survey on a regular basis. Guam might also benefit from the allure of ecotourism to recruit volunteers from off the island for commitments to survey or monitor selected sites.

#### *Funding to Support Surveys*

The government of Guam could benefit from implementing a fishing license**,** if a portion of any generated revenue were used to support surveys and management efforts for aquatic invasive species. Fees assessed to those who wish to profit from importing nonindigenous species is a demonstrated mechanism to advance management efforts (McNeely et al. 2001). Additional potential funding mechanisms are discussed below under *Management*.

#### *Intercepting Animals Illegally Shipped for Food*

Early detection of new introductions of nonindigenous species could be accomplished using the above approaches regardless of the pathway of introduction. Additionally, improved detection of species with potential to be intentionally introduced for food could be accomplished by means of periodic visits to markets and restaurants that sell live fish and other aquatic animals.

In cases of suspected illegal live or fresh animal products or species of questionable identity, DAWR personnel and other authorities are encouraged to collect whole-animal and tissue samples (for possible genetic analysis) using appropriate preservation techniques, and to have these samples examined and identified by qualified experts. If qualified experts cannot be found to accept specimens immediately, good-quality photographs of live animals will improve the chances that accurate identifications can be made. Freezing of any specimen(s) is preferable to discarding or releasing it (them).

## Management

### Prevention

Preventing transport or import of potentially harmful species so as to thwart their possible introduction or spread into new areas is generally considered to be the most efficient and cost effective way to manage invasive species (Simberloff 1998; Wittenberg and Cock 2001; Lodge et al. 2006).

Cooperation among nations in the western Pacific, whereby preventive measures are enacted to reduce the probability of exporting or importing invasive species, may benefit each nation by reducing the probability of additional nonindigenous taxa becoming established (McNeely et al. 2001). Such an approach has been implemented by Australia and its neighbors, as the North Australian Quarantine Strategy (Pheloung 2003), which involves surveillance and monitoring by all participating nations. A proactive, precautionary approach is preferred, requiring effective and coordinated efforts together with sufficient resources and networking (Henderson and Bomford 2011). Similar cooperation is encouraged between Guam, the

Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, the Republic of Palau, the Republic of Kiribati, the Republic of the Marshall Islands, the Republic of Nauru, Japan, Wake Island, Hawaii, and the U.S. mainland. There currently exists heightened awareness of invasive species in insular regions of the Pacific; consequently, a certain degree of networking and coordination is already in place.

Prevention requires that all pathways of introduction be identified and evaluated. For Guam and other insular areas in the western Pacific, the primary human-mediated dispersal pathways of nonindigenous aquatic animals are thought to be the ornamental pet trade and the aquaculture industry. The risks associated with different pathways vary among the various islands, depending in part on the scope and effectiveness of existing legal measures already in place.

### Dispensing of Unwanted Aquarium Pets

Wittenberg and Cock (2001) describe options of what to do with aquarium fish that are no longer wanted by their owners. A few of the options include returning unwanted fish to the pet store of origin, donating to another hobbyist or a corporate or public aquarium, or giving unwanted animals to a public institution such as a school, nursing home, hospital, or prison.

If none of these options are available, fish may be euthanized by placing them in a container of water and putting the container in a freezer. Humane treatment can be accomplished by exposing fish to carbon dioxide (released by use of effervescent antacid tablets such as Alka-Seltzer®) or clove oil prior to freezing. Instructions for humane lethal treatments could be included in educational materials. Another alternative would be for DAWR to establish a program whereby the agency could accept unwanted fish or other aquatic life and humanely dispose of animals or distribute them to other owners who are capable of providing proper care. As an example, the Florida Fish and Wildlife Conservation Commission holds Non-native Amnesty Days at which time pet owners can relinquish unwanted pets (*http://myfwc.com/wildlifehabitats/non-native_amnestydayevents.htm*). DAWR is encouraged to consider adopting a similar program and to offer adequate numbers of sites, annual dates, and to sufficiently publicize events to ensure success.

### Eradication

Eradication of an established freshwater fish population in a stream or river system is often difficult, and in many situations, impossible. Most successful eradication attempts rely heavily on the use of fish toxicants, mainly rotenone, but these chemicals must be used judiciously because they are largely non-selective and result in loss of both native and nonindigenous species (Kolar et al. 2011; Nico and Walsh 2011). In Guam, rotenone could possibly be used to eliminate nonindigenous fishes from certain closed systems; for example, abandoned aquaculture facilities or small ponds on golf courses where native species are absent. Reviews of eradication projects targeting invasive fishes, including eradication attempts on Pacific Islands, are included in the publications cited above.

## Containment and Control

Containment is a means to prevent the spread of a nonindigenous species. Containment in a river system may be achieved by preventing a species from passing upstream or downstream beyond a natural or artificial physical barrier, or preventing the species from passing from one watershed to another. Salinity may naturally prevent a freshwater species from dispersing among river basins. Drainage alteration that connects two or more previously separated watersheds during land development or flood control is one way in which a contained species might spread. Consideration of this possibility should be given during the construction phase of the U.S. military build-up in Guam.

Control of nonindigenous species involves reducing the density and abundance to acceptable levels. For nonindigenous species in river habitats, control and eradication may simply be matters of degree, as the methods used will largely be the same. However, control measures can sometimes fail and result in increased abundance of a target species if density-dependent population mechanisms are present (Zipkin et al. 2009). These authors stated that "species with high per capita fecundity (over discrete breeding periods), short juvenile stages, and fairly constant survivorship rates are most likely to respond undesirably to harvest."

## Legislative Actions

DAWR white list only permits those species that are allowed to be legally imported into Guam. It is our understanding that no legislation currently exists that prohibits ownership of species that are not permitted for legal importation. It is possible that Guam authorities may wish to review existing legislation and consider possible benefits of laws that could apply to possession of live animals that are otherwise illegal to import (especially given the "leaky" pathways by which undeclared shipments can potentially bypass ordinary inspection procedures). Exclusionary precedents exist; for instance, the commercial aquarium in Tumon receives official permission to maintain certain prohibited species for display and educational purposes. Legislative actions could include incentives for disclosure of potentially invasive captive-held species, such as establishing the aforementioned "amnesty" program whereby live animals could be voluntarily surrendered.

## Aquaculture Industry

Species introduced for aquaculture may escape and become established in the wild. Flooding of aquaculture facilities, in particular, may allow animals to escape (Nico et al. 2005). Nonindigenous species used for aquaculture may also carry nonindigenous disease organisms that can reduce populations of native species as well as captive animals (Funge-Smith and Briggs 2005). The following measures may help to prevent animals from escaping from aquaculture facilities (Fuller 2003; Tucker and Hargreaves 2008):

- Careful inspection to ensure that stock is not contaminated with unintended species (see also Nico et al. 2005).
- Avoid placing facilities within areas prone to flooding (e.g., 100-year floodplain).
- Install perimeter berms and fencing to secure the facility.
- Use strong and durable construction materials.

- Use appropriate mooring systems.
- Use closed circulation systems so that no water leaves the facility, or install other barriers to prevent escapement.
- Use nets or other devices to prevent birds and other predators from transporting fish away from the facility.
- Regularly inspect containment facilities.

Some species, especially those that pose the greatest threat if they escape into the wild, may be best maintained in aquaculture facilities or farm ponds as entire stocks of certified triploids or sterile hybrids. Triploid fish contain three sets of chromosomes in cell nuclei instead of the usual two sets and are considered sterile (Nico et al. 2005). Use of native species is also encouraged.

Triploid carp are commonly used for biocontrol and other purposes so that the stocked carp do not form wild reproducing populations. However, this approach may not be 100% effective at preventing carp from establishing wild breeding populations because some individuals presumed to be triploid may actually be diploid and capable of breeding (Nico et al. 2005). Possibly, triploid tilapia (Hussain et al. 1991; Byamungu et al. 2001; El-Sayed 2006) could be used in aquaculture facilities in Guam and elsewhere in Micronesia outside of government controlled, biosecure, closed-circulation breeding facilities. However, use of triploids for some species could increase production costs to the point that rearing of these species becomes economically unfeasible.

In addition to the above measures, facilities that are located at isolated sites with no connection to natural waterways reduce chances of accidental escapements of undesirable species. This may be considered a form of closed circulation. Facilities that are inspected regularly, followed with routine repairs and maintenance, provide greatest biosecurity. Data regarding the number and location of all existing and recently closed aquaculture facilities in Guam were not available to the investigators. A database containing the locations and information about the owners or former owners of these facilities would improve tracking of aquaculture activities. Facilities that are no longer in operation may remain a risk for nonindigenous species introductions if stocked animals were not previously removed and/or if perimeter barriers are no longer maintained.

There are many sources of information readily available that provide biosecurity guidance for the aquaculture sector, such as the review by Tucker and Hargreaves (2008). Local and regional regulatory authorities are encouraged to provide summaries of these resources, and recommended management alternatives, to private and commercial aquaculturists.

### Intentional Introductions for Food

Freshwater fish and other aquatic species form a large part of the diet of some ethnic groups living in Guam and elsewhere throughout Micronesia. It is likely that some nonindigenous species have become established on Pacific islands after being imported and intentionally released to provide a source of live food favored by particular ethnic groups. The population of Guam currently consists of people from many different ethnic backgrounds, and that trend is likely to continue with new immigrants (Table 37).

Table 37. Projected ethnic background of human population of Guam for 2011, 2015, and 2020. Figures in parenthesis under Native Hawaiian and other Pacific Islander include Chamorro population. Those under Asian refer to Filipino population (Guam Bureau of Statistics and Plans 2009).

| Ethnic Origin | 2011 | 2015 | 2020 |
|---|---|---|---|
| Native Hawaiian and other Pacific Islander | 81,649 | 85,762 | 90,629 |
| | (67,763) | (71,176) | (75,215) |
| Asian | 59,522 | 62,520 | 66,068 |
| | (48,168) | (50,594) | (53,466) |
| White | 12,429 | 13,054 | 13,795 |
| Black or African American | 1,854 | 1,948 | 2,058 |
| Other, single race or ethnic group | 2,137 | 2,245 | 2,372 |
| Other, mixed race or ethnic group | 25,490 | 26,774 | 28,293 |
| **Total** | 203,216 | 192,302 | 183,081 |

The likelihood of additional nonindigenous species being illegally brought to Guam and/or elsewhere in Micronesia for live food may in part depend on the ethnic composition of the construction work force that will be involved in the military build-up. Thus, projections by the government of Guam and the DoD on the anticipated ethnic composition of the civilian workforce may be beneficial in assessing risk associated with this pathway of potential introductions.

As nonindigenous fish species are not allowed to be released in Guam, the best measures to prevent intentional introductions of nonindigenous species for live food will be enforcement efforts by border control and customs inspectors, and public education, similar to the approaches described above for aquarium species.

### Baitfish

No nonindigenous freshwater fish species are sold legally as bait in Guam (B. Tibbatts, oral commun., 2010). Any future consideration of importation of baitfish should be thoroughly vetted.

### Biocontrol

No nonindigenous freshwater fish species are currently used legally for biocontrol in Guam (B. Tibbatts, oral commun., 2010). In the past, some species were introduced into Fena Reservoir on the U.S. Naval Magazine for aquatic plant control. Additionally, various poeciliid fishes may have been released in the past in Guam and other Micronesian islands to aid in insect control. As with baitfish, any considerations to introduce aquatic species as biocontrol agents should be thoroughly vetted, drawing on the expertise of scientists and government agencies to fully assess all possible consequences that would ensue through such introductions.

### Contingency Plan and Rapid Response

A contingency plan is a course of action to be taken when a new introduction has been detected or suspected (Wittenberg and Cock 2001). The first step in Guam likely would be for any person finding a fish or other aquatic species to contact one of the island's recognized authorities (e.g., Mr. Brent Tibbatts, Fisheries Biologist with DAWR, or Dr. Frank Camacho or Dr. Terry Donaldson, University of Guam). Any specimens that are available should be provided to DAWR or deposited into the biological collections at the University of Guam or another appropriate institution. Once a specimen has been positively identified or a report of a suspected new introduction has been received, personnel must then decide upon the most appropriate and effective management action to be taken. The four main management strategies described by Wittenberg and Cock (2001) are eradication, containment, control, and mitigation. These strategies will likely be the same regardless of the pathway of introduction except for intentional introductions for food, which might involve law enforcement. Officials of DAWR and other agencies are encouraged to develop a rapid response program for the early detection and management strategy for new introductions of aquatic species.

### Liability

Individuals responsible for releasing an invasive species can bear responsibility to pay all or a portion of the resulting economic costs (McNeely et al. 2001). However, individual(s) responsible have to be identified. Also, endorsement of such punitive action requires public support. In practice, costs may be so high as to bankrupt many individuals. Businesses that import or use invasive species may need to carry liability insurance (McNeely et al. 2001). The cost of such insurance could potentially render aquaculture to be economically unfeasible. Perrings et al. (2005) suggested using tariffs to have exporters of nonindigenous species pay costs incurred by those species that become invasive. Jenkins (2002) suggested fees charged to intercontinental importers and cited California's Ballast Water Management and Control Program as a possible model (*www.boe.ca.gov/sptaxprog/bllstweb12.htm*).

As the population of Guam increases, the popularity of home aquaria is expected to increase proportionally. Therefore, propagule pressure in the form of greater numbers of nonindigenous organisms in the pathway, and greater numbers of people likely to release fish to the wild, will also increase proportionally. The most successful management actions to mitigate for this increased propagule pressure will likely require improved public education, refinement of permitted species, and increased inspections and monitoring of imports.

## Education

The mainland U.S. chain pet store PetsMart discourages buyers of pet fish from releasing their pets by printing slogans directly on the bags in which customers transport their purchased fish home. This is done as part of a national campaign called “Habitattitude” (*http://www.habitattitude.net/*). This program is a partnership between the pet and aquarium trade (Pet Industry Joint Advisory Council), nursery and landscape trade, the U.S. Fish and Wildlife Service, and the National Sea Grant Program. Pet stores in Guam that sell aquatic animals and plants could be encouraged to participate in this program and to use similar bags. We asked personnel at two pet stores in Guam what measures they currently take, or would be willing to take, to discourage their customers from releasing pet fish, but staff at neither store responded.

Aquarium fish are often sold under non-standardized names. We suggest that pet stores consider labeling their stock with current valid scientific names in addition to whatever trade names they use. Scientific names could be placed on aquaria containing each species and could be visible to customers and potential inspectors. Qualified personnel of DAWR, inspection agents, and university faculty are encouraged to work closely with pet stores to achieve this and to ensure that names are kept up to date. Regular workshops could be conducted or on-site visits made to pet stores to educate store managers and their employees.

Pet store customers could be surveyed to estimate their likelihood or history of releasing animals that they purchase(d) and the reasons they do so (Gertzen et al. 2008). This information could be used to estimate the number of nonindigenous species released into Guam annually, another measure of propagule pressure, and directly related to the probability that a nonindigenous species will become established in Guam. Polled individuals could be provided with assurances of complete anonymity to prevent any possible fear of recrimination and to ensure that information is provided openly and honestly.

A website could be constructed with information about invasive aquatic species and the threats that they pose to native species and habitats. Through such a web site, the aforementioned posters and videos could be made freely available for downloading and printing. Such a website could be designed so that it appears at, or very near, the top of the list of links returned by casual searches conducted by means of Internet search engines by use of strategic key words.

## Research Needs

Some authors have reported that little evidence exists concerning the negative effects of nonindigenous fish species on native species in their regions or countries, or that relatively little research has been directed in this area (Luu and VanThanh 2005; Nuov et al. 2005; Win 2005). However, there are many well documented cases that illustrate how introduced freshwater fishes have negative consequences on native faunas—in some examples on a community level or large landscape scale (e.g., the Laurentian Great Lakes, the Colorado River basin, and Lake Victoria). In the case of Micronesia, we are aware of few studies that have directly examined interactions between nonindigenous and native species. McKagan et al. (2009) reported results of an extensive survey for nonindigenous aquatic species on Saipan, and included information from FishBase (*http://www.fishbase.org*) that summarized potential threats. MacKenzie and Bruland found that introduced poeciliid fishes posed threats to wetland habitats in Hawaii. Tilapias, which were intentionally introduced to many Pacific islands to provide food (Devambez 1964), are now commonly regarded as pests in many places and may have impacts on native species broadly across aquatic habitats from fresh water to coral atolls (Gillett 1990; Nelson and Eldredge 1991; Canonico et al. 2005). We suggest that additional research into effects of nonindigenous species on native species in Micronesia would be helpful in prioritizing management efforts, albeit a precautionary approach is best in the absence of scientific evidence of effects (Bartley et al. 2005). Other authors have similarly suggested the need for additional empirical research on the general topic of how nonindigenous species affect native species in areas where they become invasive (Hager and McCoy 1998; Gurevitch and Padilla 2004; Didham et al. 2005).

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## References Cited


ABRPI (Aquatic Bioinvasion Research and Policy Institute). 2011. Biosecurity plan for freshwater invasive plants in Micronesia. Portland State University, Portland, OR, 135 p.

Adams, C. M., S. L. Larkin, R. L. Degner, D. J. Lee, and J. W. Milon. 2001. International trade in live, ornamental “fish” in the U.S. and Florida. Unpublished report, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Agresti, A. 2002. Categorical data analysis. 2nd edition. John Wiley & Sons, Inc., Hoboken, NJ.

Alcaraz, C., A. Vila-Gispert, and E. García-Berthou. 2005. Profiling invasive fish species: the importance of phylogeny and human use. Diversity and Distributions 11:289-298.

Alfaro, R. E. M., B. Cudmore, R. Orr, J. P. Fisher, S. C. Balderas, W. R. Courtenay, P. K. Osorio, N. Mandrak, P. A. Torres, M. A. Damián, C. E. Gallardo, A. G. Sanguinés, G. Greene, D. Lee, A. Orbe-Mendoza, C. R. Martinez, and O. S. Arana. 2009. Trinational risk assessment guidelines for aquatic alien invasive species; test cases for the snakeheads (Channidae) and armored catfishes (Loricariidae) in North American inland waters. Commission for Environmental Cooperation Project Report.

Allen, G. R. 1974. The marine crocodile, *Crocodylus porosus*, from Ponape, Eastern Caroline Islands, with notes on food habits of crocodiles from the Palau archipelago. Copeia 1974:553.

Anthony, S. S. 1991. Hydrogeology and ground-water resources of Kahlap Island, Mwoakilloa Atoll, State of Pohnpei, Federated States of Micronesia. U.S. Geological Survey Water-Resources Investigations Report 91-4184.

Anthony, S. S. 1992. Hydrogeology and ground-water resources of Pingelap Island, Pingelap Atoll, State of Pohnpei, Federated States of Micronesia. U.S. Geological Survey Water-Resources Investigations Report 92-4005.

Anthony, S. S. 1993. Hydrogeology and ground-water resources of Ngatik Island, Sapwuahfik Atoll, State of Pohnpei, Federated States of Micronesia. U.S. Geological Survey Water-Resources Investigations Report 93-4117.

Anthony, S. S. and S. R. Spengler. 1993. Geology and water-resources reconnaissance of Lenger Island, State of Pohnpei, Federated States of Micronesia, 1991. U.S. Geological Survey Water-Resources Investigations Report 93-4217.

Atoda, K. 1950. Metamorphosis of the "non-aquatic frog" of the Palau Islands, western Carolines. Pacific Science 4:202-207.

Bartley, D. M., F. J. B. Marttin, and M. Halwart. 2005. FAO mechanisms for the control and responsible use of alien species in fisheries, *in* D. M. Bartley, R. C. Bhujel, S. Funge-Smith, P. G. Olin, and M. J. Phillips (ed.), International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation, Xishuangbanna, People's Republic of China, 27-30 August 2003, FAO, Rome, Italy.

Best, B.R. 1981. Bibliography of inland aquatic ecosystems of the Marianas archipelago. University of Guam Marine Laboratory Technical Report 72, Seattle National Fishery Research Center, Seattle, 64 p.

Best, B.R. and C.E. Davidson. 1981. Inventory and atlas of the inland aquatic ecosystems of the Marianas archipelago. University of Guam Marine Laboratory Technical Report 75, Seattle National Fishery Research Center, 238 p.

Blackburn, T. M., P. Cassey, and J. L. Lockwood. 2009. The role of species traits in the establishment success of exotic birds. Global Change Biology 15:2852-2860.

Bomford, M. 2003. Risk assessment for the import and keeping of exotic vertebrates in Australia. Bureau of Rural Sciences, Canberra. *http://www.affa.gov.au/brs*.

Bomford, M. 2008. Risk assessment models for establishment of exotic vertebrates in Australia and New Zealand. Invasive Animals Cooperative Research Centre, Canberra, Australia, 191 p.

Bomford, M., S. C. Barry, and E. Lawrence. 2010. Predicting establishment success for introduced freshwater fishes: a role for climate matching. Biological Invasions 12:2559-2571.

Bomford, M., F. Kraus, S. C. Barry, and E. Lawrence. 2009. Predicting establishment success for alien reptiles and amphibians: a role for climate matching. Biological Invasions 11:713–724.

Bright, G. R. 1989. The freshwater decapod crustaceans of Yap, Caroline Islands. University of Guam Marine Laboratory Technical Report No. 92:33-36.

Bright, G. R. and J. A. June. 1981. Freshwater fishes of Palau, Caroline Islands. Micronesica 17:107-111.

Brock, V.E. and M. Takata. 1956. A limnological resurvey of Fena River Reservoir, Guam, Marianas Islands. Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii, 9 p.

Buck, E.H. 2009. Ballast water management to combat invasive species. CRS Report for Congress, Congressional Research Service 7-5700, 1-11 p.

Buden, D. W. 2000. The reptiles of Pohnpei, Federated States of Micronesia. Micronesica 32:155-180.

Buden, D. W. 2004. The Odonata of Pakin, Ant, Mokil, and Pingelap Atolls, Eastern Caroline Islands, Micronesia. Micronesica 37:145-155.

Buden, D. W. 2007. Reptiles of Satawan Atoll and the Mortlock Islands, Chuuk State, Federated States of Micronesia. Pacific Science 61:415-428.

Buden, D. W., D. B. Lynch, J. W. Short, and T. Leberer. 2001a. Decapod crustaceans of the headwater streams of Pohnpei, eastern Caroline islands, Federated States of Micronesia. Pacific Science 55:257-265.

Buden, D. W., D. B. Lynch, and R. E. Watson. 2001b. The gobiid fishes (Teleostei: Gobioidei: Sicydiinae) of the headwater streams of Pohnpei, eastern Caroline Islands, Federated States of Micronesia. Micronesica 34:1-10.

Buden, D. W., D. B. Lynch, and G. R. Zug. 2001c. Recent records of exotic reptiles on Pohnpei, eastern Caroline Islands, Micronesia. Pacific Science 55:65-70.

Buden, D. W. and D. R. Paulson. 2003. The Odonata of Kosrae, Eastern Caroline Islands, Micronesia. Pacific Science 57:399-407.

Buden, D. W. and D. R. Paulson. 2007. Odonata of Yap, Western Caroline Islands, Micronesia. Pacific Science 61:267-277.

Burnham, K. P. and D. A. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer Science & Business Media, Inc., New York, NY.

Byamungu, N., V. M. Darras, and E. R. Kühn. 2001. Growth of heat-shock induced triploids of blue tilapia, *Oreochromis aureus*, reared in tanks and in ponds in eastern Congo: feeding

regimes and compensatory growth response of triploid females. Aquaculture 198:109-122.
Calado, R. and P. M. Chapman. 2006. Aquarium species: deadly invaders. Marine Pollution Bulletin 52:599-601.
Canonico, G. C., A. Arthington, J. K. McCrary, and M. L. Thieme. 2005. The effects of introduced tilapias on native biodiversity Aquatic Conservation: Marine and Freshwater Ecosystems 15:463-483.
Carruth, R.L. 2003. Ground-water resources of Saipan, Commonwealth of the Northern Mariana Islands. U.S. Geological Survey Water-Resources Investigations Report 03-4178. Carruth, R.L. 2005. Construction, geologic, and hydrologic data from five exploratory wells on Rota, Commonwealth of the Northern Mariana Islands, 1999. U.S. Geological Survey Open-File Report 2005-1042, 40 p.
Casal, C. M. V. 2006. Global documentation of fish introductions: the growing crisis and recommendations for action. Biological Invasions 8:3-11.
Chace, F. A., Jr. 1983. The *Atya*-like shrimps of the Indo-Pacific region (Decapoda: Atyidae). Smithsonian Contributions to Zoology 384:1-54.
Chapman, F. A., S. A. Fitz-Coy, E. M. Thunberg, and C. M. Adams. 1997. United States of America trade in ornamental fish. Journal of the World Aquaculture Society 28:1-10.
Christy, M. T., C. S. Clark, D. E. Gee II, D. Vice, D. S. Vice, M. P. Warner, C. L. Tyrrell, G. H. Rodda, and J. A. Savidge. 2007a. Recent records of alien anurans on the Pacific island of Guam. Pacific Science 61:469-483.
Christy, M. T., J. A. Savidge, and G. H. Rodda. 2007b. Multiple pathways for invasion of anurans on a Pacific island. Diversity and Distributions 13:598-607.
Clay, J. W. 2008. The role of better management practices in environmental management, Pages 55-72 *in* C. S. Tucker and J. A. Hargreaves (ed.), Environmental best management practices for aquaculture. Blackwell Publishing, Ames, IA.
CNMI-UWAWG (CNMI Unified Watershed Assessment Working Group). 1998. Unified watershed assessment. CNMI Division of Environmental Quality and other agencies, 50 p.
Colautti, R. I., I. A. Grigorovich, and H. J. MacIsaac. 2006. Propagule pressure: a null model for biological invasions. Biological Invasions 8:1023-1037.
Cole, B., C. S. Tamaru, R. Bailey, C. Brown, and H. Ako. 1999. Shipping practices in the ornamental fish industry. Center for Tropical and Subtropical Aquaculture Publication 131.
Conover, G., R. Simmonds, and M. Whalen. 2007. Management and control plan for bighead, black, grass, and silver carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, D.C., 223 p. *http://www.asiancarp.org/documents/Carps_Management_Plan.pdf*.
Copp, G. H., M. Templeton, and R. E. Gozlan. 2007. Propagule pressure and the invasion risks of non-native freshwater fishes: a case study in England. Journal of Fish Biology 71:148-159.

Courtenay, W. R., Jr. 1994. Current major pathways of fish introductions, *in* D. C. Schmitz and T. C. Brown (ed.), An assessment of invasive non-indigenous species in Florida's public lands. Florida Department of Environmental Protection, Tallahassee, Florida.

Courtenay, W. R., Jr. and J. R. Stauffer, Jr. 1990. The introduced fish problem and the aquarium fish industry. Journal of the World Aquaculture Society 21:145-159.

Courtenay, W. R. J. 1999. Aquariums and water gardens as vectors of introduction, Pages 127-128 *in* R. Claudi and J. H. Leach (ed.), Nonindigenous freshwater organisms: vectors, biology, and impacts. Lewis Publishers, Boca Raton, FL.

Cowie, R. H. 1998a. Homogenization of Pacific island snails. World Conservation: Quarterly Bulletin of IUCS--the World Conservation Union 4/97-1/98:18.

Cowie, R. H. 1998b. Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian islands. Biodiversity and Conservation 7:349-368.

Cowie, R.H. 2000a. Non-indigenous land and freshwater molluscs in the islands of the Pacific: conservation impacts and threats. Invasive species in the Pacific: a technical review and regional strategy, South Pacific Regional Environment Programme, Apia, Samoa, 143-172 p.

Cowie, R. H. 2000b. Non-indigenous land and freshwater molluscs in the islands of the Pacific: conservation impacts and threats. Hawaii Biological Survey Contribution No. 1999-010, Pacific Biological Survey Contribution 2000-005.

Cowie, R. H. 2002. Apple snails (Ampullariidae) as agricultural pests: their biology, impacts and management, Pages 145-192 *in* G. M. Barker (ed.), Molluscs as crop pests. CAB International, Oxfordshire, U.K.

Cowie, R. H., K. A. Hayes, and C. T. Tran. 2007. Distribution of the invasive apple snail *Pomacea canaliculata* (Lamarck) in the Hawaiian Islands (Gastropoda: Ampullariidae). Bishop Museum Occasional Papers 96 96:48-51.

Cowie, R. H., J. Robert, T. Dillon, D. G. Robinson, and J. W. Smith. 2009. Alien non-marine snails and slugs of priority quarantine importance in the United States: a preliminary risk assessment. American Malacological Bulletin 27:113-132.

Crawley, M. J. 1986. The population biology of invaders. Philosophical Transactions of the Royal Society B: 314:711-731.

Crombie, R. I. and G. K. Pregill. 1999. A checklist of the herpetofauna of the Palau islands (Republic of Belau), Oceania. Herpetological Monographs 13:29-80.

CTSA (Center for Tropical and Subtropical Aquaculture). 2010. 2010 accomplishment report. Oceanic Institute and University of Hawaii at Manoa, Waimanalo and Honolulu, HI, 180 p.

Daehler, C. C., J. S. Denslow, S. Ansari, and H.-C. Kuo. 2004. A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific islands. Conservation Biology 18:360-368.

Daehler, C. C. and D. R. Strong, Jr. 1993. Prediction and biological invasions. Trends in Ecology and Evolution 8:380.

Dahl, C. R. 1993. The Federated States of Micronesia, Pages 45-71 *in* D. A. Scott (ed.), A directory of wetlands in Oceania. IWRB, Slimbridge, U.K. and AWB, Kuala Lumpur, Malaysia.

De Silva, S.S., R.P. Subasinghe, D.M. Bartley, and A. Lowther 2004. Tilapias as alien aquatics in Asia and the Pacific: a review. FAO Fisheries Technical Paper. No. 453, Food and Agriculture Organization of the United Nations, Rome, 65 p.

Devambez, L. C. 1964. Tilapia in the South Pacific. South Pacific Bulletin 14 4:27,28, and 52.

Devick, W. S. 1991. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. Pages 189-213 *in* New directions in research, management and conservation of Hawaiian freshwater stream ecosystems. Proceedings of the 1990 symposium on freshwater stream biology and fisheries management, Honolulu, HI.

Didham, R. K., J. M. Tylianakis, M. A. Hutchison, R. M. Ewers, and N. J. Gemmell. 2005. Are invasive species the drivers of ecological change? Trends in Ecology & Evolution 20:470-474.

Donaldson, T. J. and R. F. Myers. 2002. Insular freshwater fish faunas of Micronesia: patterns of species richness and similarity. Environmental Biology of Fishes 65:139-149.

Drake, J. M. and D. M. Lodge. 2004. Global hot spots of biological invasions: evaluating options for ballast-water management. Proceedings of the Royal Society of London B 271:575-580.

Drake, J. M., D. M. Lodge, and M. Lewis. 2005. Theory and preliminary analysis of species invasions from ballast water: controlling discharge volume and location American Midland Naturalist 154:459-470.

Duggan, I. C., C. A. M. Rixon, and H. J. MacIsaac. 2006. Popularity and propagule pressure: determinants of introduction and establishment of aquarium fish. Biological Invasions 8:377-382.

Easteal, S. 1981. The history of *Bufo marinus* (Amphibia: Anura): a natural experiment in evolution. Biological Journal of the Linnean Society 16:93-113.

Ehrlich, P. R. 1986. Which animals will invade?, Pages 79-95 *in* H. A. Mooney and J. A. Drake (ed.), Ecology of biological invasions in North America and Hawaii. Springer-Verlag, New York, NY.

Ehrlich, P. R. 1989. Attributes of invaders and the invading processes: vertebrates, Pages 315-328 *in* J. A. Drake and H. A. Mooney (ed.), Biological invasions: a global perspective. John Wiley & Sons, Chichester, NY.

El-Sayed, A.-F. M. 2006. Tilapia culture. CABI, Oxfordshire, U.K.

Eldredge, L.G. 1994. Introductions of commercially significant aquatic organisms to the Pacific islands. Perspectives in Aquatic Species Management in the Pacific Islands, Vol. 1, South Pacific Commission, SPREP Report and Studies Series No. 78, Noumea, New Caledonia, 127 p. *http://www.spc.int/Coastfish/Reports/IFRP/Introd/Eldredge.pdf*.

Eldredge, L. G. 2000. Non-indigenous freshwater fishes, amphibians, and crustaceans of the Pacific and Hawaiian islands. Hawaii Biological Survey Contribution No. 1999-011, Pacific Biological Survey Contribution 2000-007:173-190.

Ellison, J. C. 2009. Wetlands of the Pacific Island region. Wetlands Ecology and Management 17:169-206.

Englund, R. A. 2002. The loss of native biodiversity and continuing nonindigenous species introductions in freshwater, estuarine, and wetland communities of Pearl Harbor, Oahu, Hawaiian islands. Estuaries 25:418–430.

Englund, R. A. and Y. Cai. 1999. The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands. Bishop Museum Occasional Papers 58:58-62.

Ernst, C. H. and J. E. Lovich. 2009. Turtles of the United States and Canada, 2nd edition. Johns Hopkins University Press, Baltimore, Maryland.
Eschmeyer, W.N., 2011, Catalog of fishes: California Academy of Sciences. *http://research.calacademy.org/redirect?url=http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp*.
Evenhuis, N. L. and J. M. Fitzsimons (eds.). 2005. Biology of Hawaiian streams and estuaries. Proceedings of the symposium on the biology of Hawaiian streams and estuaries, Bishop Museum Press, Hilo, Hawai‘i, 334 p. *http://hbs.bishopmuseum.org/pubs-online/strm/bces3.html*.
Fehlmann, H. A. 1960. Ecological distribution of fishes in a stream drainage in the Palau islands. Ph.D. dissertation. Standford University, Palo Alto, California.
Fernandez, L. 2008. NAFTA and member country strategies for maritime trade and marine invasive species. Journal of Environmental Management 89:308-321.
FitzGerald W.J. 1982. Aquaculture development plan for the Territory of Guam. Department of Commerce, Government of Guam, 209 p.
Fitzgerald, W. J., Jr. and S. G. Nelson. 1979. Development of aquaculture in an island community (Guam, Mariana Islands). Proceedings of the World Mariculture Society 10:39-50.
Fitzsimons, J. M., M. G. McRae, and R. T. Nishimoto. 2007. Behavioral ecology of indigenous stream fishes in Hawai'i, Pages 11-21 *in* N. L. Evenhuis and J. M. Fitzsimons (ed.), Proceedings of the Symposium on the Biology of Hawaiian Streams and Estuaries. Bishop Museum Press, Honolulu, HI.
Fitzsimons, J. M., J. E. Parham, and R. T. Nishimoto. 2002. Similarities in behavioral ecology among amphidromous and catadromous fishes on the oceanic islands of Hawai'i and Guam. Environmental Biology of Fishes 65:123-129.
Fofonoff, P. W., R. Ruiz-Carus, B. Steves, and J. T. Carlton. 2003. In ships or on ships? Mechanisms of transfer and invasion for nonnative species to the coasts of North America, Pages 152-182 *in* G. M. Ruiz and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Ford, J. I. and R. A. Kinzie, III 1982. Life crawls upstream. Natural History 91:391-395.
Franklin, J. 2009. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, U.K.
Froese, R. and D. Pauly. 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines.
Froese, R. and D. Pauly. 2011. FishBase, *http://www.fishbase.org.* Accessed April 2011.
Fujisaki, I., K. M. Hart, F. J. Mazzotti, K. G. Rice, S. Snow, and M. Rochford. 2009. Risk assessment of potential invasiveness of exotic reptiles imported to south Florida. Biological Invasions 12:2585-2596.
Fuller, P. 2003. Freshwater aquatic vertebrate introductions in the United States: patterns and pathways, p. 518 *in* G. M. Ruiz and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, MD.
Funge-Smith, S. and M. Briggs. 2005. The introduction of *Penaeus vannamei* and *P. stylirostris* into the Asia-Pacific region, *in* D. M. Bartley, R. C. Bhujel, S. Funge-Smith, P. G. Olin, and M. J. M.J. Phillips (ed.), International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation,

Xishuangbanna, People's Republic of China, 27-30 August 2003, FAO, Rome, Italy.
García-Berthou, E. 2007. The characteristics of invasive fishes: what has been learned so far? Journal of Fish Biology 71:33-55.
DAWR (Guam Division of Aquatic and Wildlife Resources). 2006. Guam comprehensive wildlife conservation strategy (GCWCS). Guam Division of Aquatic and Wildlife Resources, Mangilao, Guam, 259 p.
Gelman, A. and J. Hill. 2007. Data analysis using regression and multilevel/hierarchical models, Cambridge, UK.
Gertzen, E., O. Familiar, and B. Leung. 2008. Quantifying invasion pathways: fish introductions from the aquarium trade. Canadian Journal of Fisheries and Aquatic Sciences 65:1265-1273.
Gillett, R. 1990. Tilapia in the Pacific islands: are there lessons to be learned? South Pacific Commission Fisheries Newsletter 49:27-30.
Gingerich, S. B. 2003. Hydrologic resources of Guam. U.S. Geological Survey Scientific Investigations Report 2003-4126:3.
Goldstein, R. M. and T. P. Simon. 1999. Toward a united definition of guild structure for feeding ecology of North American freshwater fishes, Pages 123- *in* T. P. Simon (ed.), Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, FL.
Guam Bureau of Statistics and Plans. 2009. Guam statistical yearbook 2008. 445 p.
Gurevitch, J. and D. K. Padilla. 2004. Are invasive species a major cause of extinctions? Trends in Ecology and Evolution 19:470-474.
GWADF (Government of Western Australia Department of Fisheries ). 2009. A review: biosecurity risks posed by vessels and mitigation options. Fisheries Occasional Publication No.55, Government of Western Australia Department of Fisheries, 24 p. *http://www.fish.wa.gov.au/docs/op/op055/index.php?0706*.
Hager, H. A. and K. D. McCoy. 1998. The implications of accepting untested hypotheses: a review of the effects of purple loosestrife (*Lythrum salicaria*) in North America. Biodiversity and Conservation 7:1069-1079.
Hamlin, S. N. and K. J. Takasaki. 1996. Water-quality reconnaissance of ground-water in the inhabited outer islands of Chuuk State, Federated States of Micronesia, 1984-85. U.S. Geological Survey Water-Resources Investigations Report 96-4180:77.
Hankin, D. G. and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.
Hayden, B. J. and C. F. Whyte. 2003. Invasive species management in New Zealand, Pages 270-291 *in* G. M. Ruiz and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Hayes, K. R. 2003. Biosecurity and the role of risk assessment, Pages 382-414 *in* G. M. Ruiz and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Hayes, K. R. and S. C. Barry. 2008. Are there any consistent predictors of invasion success? Biological Invasions 10:483-506.
Helfman, G. S. 2007. Fish conservation: a guide to understanding and restoring global aquatic biodiversity and fishery resources. Island Press, Washington, D.C.
Henderson, W. and M. Bomford. 2011. Detecting and preventing new incursions of exotic animals in Australia. Invasive Animals Cooperative Research Centre, Canberra, Australia, 54 p.

Hulme, P. E., S. Bacher, M. Kenis, S. Klotz, I. Kühn, D. Minchin, W. Nentwig, S. Olenin, V. Panov, J. Pergl, P. Pysek, A. Roques, D. Sol, W. Solarz, and M. Vilà. 2008. Grasping at the routes of biological invasions: a framework for integrating pathways into policy. Journal of Applied Ecology 45:403-414.

Hussain, M. G., A. Chatterji, B. J. McAndrew, and R. Johnstone. 1991. Triploidy induction in Nile tilapia, *Oreochromis niloticus* L. using pressure, heat and cold shocks. Theoretical and Applied Genetics 81:6-12.

Hutchison, M., R. Simpson, A. Elizur, D. Willet, and A. Collins. 2002. Restoring jungle perch *Kuhlia rupestris* recreational fisheries to south-east Queensland. Department of Primary Industries, Queensland Fisheries Service, Queensland, 10 p.

Iguchi, K. 2007. Limitations of early seaward migration success in amphidromous fishes. Bishop Museum Bulletin in Cultural and Environmental Studies 3:75-85.

Iketani, G., L. Pimentel, G. Silva-Oliveira, C. Maciel, W. Valenti, H. Schneider, and I. Sampaio. 2011. The history of the introduction of the giant river prawn, *Macrobrachium* cf. *rosenbergii* (Decapoda, Palaemonidae), in Brazil: new insights from molecular data. Genetics and Molecular Biology 34:142-151.

Jenkins, A. P., S. D. Jupiter, I. Qauqau, and J. Atherton. 2009. The importance of ecosystem-based management for conserving aquatic migratory pathways on tropical high islands: a case study from Fiji. Aquatic Conservation: Marine and Freshwater Ecosystems 20:224-238.

Jenkins, P. T. 2002. Paying for protection from invasive species. Issues in Science and Technology 19:67-72.

Jenkins, P. T. 2005. International law related to precautionary approaches to national regulation of plant imports. Journal of World Trade 39:895-906.

Kami, H. T., I. I. Ikehara, and F. P. DeLeon. 1968. Check-list of Guam fishes. Micronesica 4:95-131.

Karge, A., K. Von Rintelen, and W. Klotz. 2010. On two small collections of freshwater shrimps (Decapoda:Atyidae:*Caridina*) from Papua New Guinea, with descriptions of two new species. Zootaxa 2372:138-150.

Keith, P. 2003. Biology and ecology of amphidromous Gobiidae of the Indo-Pacific and the Caribbean regions. Journal of Fish Biology 63:831-847.

Kéry, M., J. A. Royle, M. M. Plattner, and R. M. Dorazio. 2009. Species richness and occupancy estimation in communities subject to temporary emigration. Ecology 90:1279-1290.

Kéry, M., J. A. Royle, and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications 15:1450-1461.

Kingston, P. A. 2004. Surveillance of drinking water quality in the Pacific islands: situation analysis and needs assessment. World Health Organization, Western Pacific Region, Country Reports.

Kinzie, R. A. 1990. Species profiles: life histories and environmental requirements of coastal vertebrates and invertebrates Pacific Ocean region, report 3, amphidromous macrofauna of Hawaiian island streams. Technical Report EL-89-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS:1-28.

Kolar, C. 2004. Risk assessment and screening for potentially invasive fishes. New Zealand Journal of Marine and Freshwater Research 38:391-397.

Kolar, C. S., W. R. Courtenay, and L. G. Nico. 2011. Managing undesired and invading fishes, Pages 000-000 *in* W. A. Hubert and M. C. Quist (ed.), Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesday, MD.

Kolar, C. S. and D. M. Lodge. 2001. Progress in invasion biology: predicting invaders. Trends in

Ecology & Evolution 16:199-204.
Kolar, C. S. and D. M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298:1233-1236.
Kraus, F. 2009a. Alien reptiles and amphibians: a scientific compendium and analysis. Springer.
Kraus, F. 2009b. Global trends in alien reptiles and amphibians. Aliens: the Invasive Species Bulletin 29:13-18.
Kraus, F. and D. C. Duffy. 2010. A successful model from Hawaii for rapid response to invasive species. Journal for Nature Conservation 18:135-141.
LaBaugh, J. W. 1985. Survey of Fena Reservoir, island of Guam--limnological reconnaissance. U.S. Geological Survey Water-Resources Investigations Report 83-4241:17 p.
Lach, L. and R. H. Cowie. 1999. The spread of the introduced freshwater apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariideae) on O'ahu, Hawai'i. Bishop Museum Occasional Papers 58:66-71.
Larson, H. K. 2010. A review of the gobiid fish genus *Redigobius* (Teleostei: Gobionellinae), with descriptions of two new species. Ichthyological Explorations of Freshwaters 21:123-191.
Leberer, T. 2003. Records of freshwater turtles on Guam, Mariana Islands. Micronesica 35-36:649-652.
Leberer, T. and Y. Cai. 2003. Shrimps of the family Atyidae from Guam, Mariana Islands. Micronesica 35-36:353-358.
Lever, C. 1996. Naturalized fishes of the world. Academic Press, London, U.K.
Lever, C. 2003. Naturalized reptiles and amphibians of the world. Oxford University Press, Oxford, U.K.
Lin, Y.-H., C.-H. Chang, I.-H. Chen, Y.-W. Chiu, S.-H. Wu, and J.-H. Chen. 2006. The survey of the imported aquatic invertebrates via the live aquarium ornamental trade in Taiwan. Taiwania 51:99-107.
Lindsay, S. 2008. Facility for economic and infrastructure management project: aquaculture and fisheries action plan. Prepared for Government of Palau and Asian Development Bank, Project TA4929-PAL, 30 p.
Lockwood, J. L., P. Cassey, and T. M. Blackburn. 2005. The role of propagule pressure in explaining species invasions. Trends in Ecology and Evolution 20:223-228.
Lockwood, J. L., M. F. Hoopes, and M. P. Marchetti. 2007. Invasion ecology. Blackwell Publishing, Malden, MA.
Lodge, D. M. 1993. Progress in invasion biology: predicting invaders. Trends in Ecology and Evolution 16:199-204.
Lodge, D. M., S. Williams, H. J. Macisaac, K. R. Hayes, B. Leung, S. Reichard, R. N. Mack, P. B. Moyle, M. Smith, D. A. Andow, J. T. Carlton, and A. McMichael. 2006. Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16:2035–2054.
LoVullo, T. J. and J. R. Stauffer, Jr. 1993. The retail bait fish industry in Pennsylvania–source of introduced species. Journal of the Pennsylvania Academy of Science 67:13-15.
Lowe, S., M. Browne, S. Boudjelas, and M. De Poorter 2004. 100 of the world's worst invasive alien species: a selection from the Global Invasive Species Database. The Invasive Species Specialist Group (ISSG), a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), Auckland, New Zealand, 12 p. *http://www.issg.org/pdf/publications/worst_100/english_100_worst.pdf*.

Ludwig, H. R., Jr. and J. A. Leitch. 1996. Interbasin transfer of aquatic biota via angler's bait buckets. Fisheries 21:14-18.
Luu, L. T. and N. VanThanh. 2005. Viet Nam national report on alien species, *in* D. M. Bartley, R.C. Bhujel, S. Funge-Smith, P.G. Olin and M. J. Phillips (ed.), International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation, Xishuangbanna, People's Republic of China, 27-30 August 2003, FAO, Rome, Italy.
Maciolek, J. A. 1983. Distribution and biology of Indo-Pacific insular hypogeal shrimps. Bulletin of Marine Science 33:608-618.
Maciolek, J. A. 1984. Exotic fishes in Hawaii and other islands of Oceania, Pages 131-161 *in* W. R. Courtenay, Jr. and J. R. Stauffer, Jr. (ed.), Biology, and management of exotic fishes. The Johns Hopkins University Press, Baltimore.
Maciolek, J. A. and J. I. Ford. 1987. Macrofauna and environment of the Nanpil-Kiepw River, Ponape, Eastern Caroline Islands. Bulletin of Marine Science 41:623-632.
MacKenzie, R. A. and G. L. Bruland. Impacts of exotic fish on biodiversity and habitat value of coastal wetlands in the Hawaiian islands. Biological Conservation (unpublished manuscript).
MacKenzie, R. A., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, Amsterdam, The Netherlands.
Madsen, H. and F. Frandsen. 1989. The spread of freshwater snails including those of medical and veterinary importance. Acta Tropica 46:139-146.
Marchetti, M. P. and P. B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11:530-539.
Marchetti, M. P., P. B. Moyle, and R. Levine. 2004a. Alien fishes in California watersheds: characteristics of successful and failed invaders. Ecological Applications 14:587-596.
Marchetti, M. P., P. B. Moyle, and R. Levine. 2004b. Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. Freshwater Biology 49:646-661.
McCoid, M. J. 1992. Geographic distribution: *Trachemys scripta*. Herpetelogical Review 23:26.
McCoid, M. J. 1993. The "new" herpetofauna of Guam, Mariana Islands. Herpetelogical Review 24:16-17.
McCoid, M. J. 1999. Established exotic reptiles and amphibians of the Mariana Islands, Pages 453-459 *in* G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka (ed.), Problem snake management: the habu and the brown tree snake. Cornell University Press, Ithaca, NY.
McDowall, R. M. 1988. Diadromy in fishes: migrations between freshwater and marine environments, London, Great Britain.
McDowall, R. M. 2004. Ancestry and amphidromy in island freshwater fish faunas. Fish and Fisheries 5:75-85.
McDowall, R. M. 2007. Hawaiian stream fishes: the role of amphidromy in history, ecology, and conservation biology, Pages 3-9 *in* N. L. Evenhuis and J. M. Fitzsimons (ed.), Proceedings of the Symposium on the Biology of Hawaiian Streams and Estuaries. Bishop Museum Press, Honolulu.
McKagan, S., J. Herod, P. Johnson, M. Tenorio, and M. Trianni. 2009. Freshwater invasive species project. Unpublished report, Division of Fish & Wildlife, Commonwealth of the Northern Mariana Islands, 86 p.

McNeely, J. A., H. A. Mooney, L. E. Neville, P. J. Schei, and J. K. Waage, editors. 2001. A global strategy on invasive alien species. IUCN, Gland, Switzerland and Cambridge, U.K.
Measham, T. G., G. J. Kelly, and F. P. Smith. 2007. Best management practice for complex problems: a case study of defining BMP for dryland salinity. Geographical Research 45:262-272.
Mink, J. F. and H. L. Vacher. 1997. Hydrogeology of northern Guam, *in* H. L. Vacher and T. Quinn (ed.), Geology and hydrogeology of carbonate islands. Developments in Sedimentology 54. Elsevier Science.
Moyle, P. B. and T. Light. 1996a. Biological invasions of fresh water: empirical rules and assembly theory. Biological Conservation 78:149-161.
Moyle, P. B. and T. Light. 1996b. Fish invasions in California: do abiotic factors determine success? Ecology 77:1666-1670.
Moyle, P. B. and M. P. Marchetti. 2006. Predicting invasion success: freshwater fishes in California as a model. BioScience 56:515-524.
Mundy, B. C. 2005. Checklist of the fishes of the Hawaiian archipelago. Bishop Museum Bulletin in Zoology 6, Honolulu, HI.
Munro, J. L. 1993. Aquaculture development and environmental issues in the tropical Pacific, Pages 125-138 *in* R. S. V. Pullin, H. Rosenthal, and J. L. Maclean (ed.), Environment and aquaculture in developing countries. ICLARM (International Center for Living Aquatic Resources Management) Conference Proceedings 31.
Myers, R. F. and T. J. Donaldson. 2003. The fishes of the Mariana Islands. Micronesica 35-36:594-648.
Mylroie, J. E. and J. L. Carew. 1995. Karst development on carbonate islands, Pages 55-76 *in* D. A. Budd, P. M. Harris, and A. Saller (ed.), Unconformities and porosity in carbonate strata. American Association of Petroleum Geologists, Tulsa, Oklahoma.
Mylroie, J. E. and J. W. Jenson. 2000. CIKM, the Carbonate Island Karst Model. Geological Society of America, conference abstracts, A-355 p.
Mylroie, J. E., J. W. Jenson, J. M. U. Jocson, and M. A. Lander. 1999. Karst geology and hydrology of Guam: a preliminary report. Water and Environmental Research Institute of the Western Pacific, University of Guam, Technical Report 89:32.
Mylroie, J. E., J. W. Jenson, D. Taboroši, J. M. U. Jocson, D. T. Vann, and C. Wexel. 2001. Karst features of Guam in terms of a general model of carbonate island karst. Journal of Cave and Karst Studies 63:9-22.
Naylor, R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. Ambio 25:443-448.
Nelson, S. G. 1988. Development of aquaculture in the U.S.-affiliated islands of Micronesia, Pages 61-83 *in* B. D. Smith (ed.), Topic reviews in insular resource development and management in the Pacific U.S.-affiliated islands, University of Guam Marine Laboratory Technical Report 88.
Nelson, S. G. (ed.). 1989a. The inland aquatic habitats of Yap. University of Guam Marine Laboratory Technical Report No. 92, 78 p.
Nelson, S. G. 1989b. A regional survey of the aquaculture sector in the Pacific. Aquaculture Development and Coordination Programme (ADCP/REP/88/32), Food and Agriculture Organization of the United Nations, Rome, 48 p.
Nelson, S. G., F. A. Camacho, J. E. Parham, R. B. Tibbatts, T. Leberer, and B. D. Smith. 1996. Surveys of the macrofauna of the Nanpil Kiepw and Lehn Mesi rivers of Pohnpei. University of Guam Marine Laboratory Technical Report 103:1-22.
Nelson, S. G. and L. G. Eldredge. 1991. Distribution and status of introduced cichlid fishes of the

genera *Oreochromis* and *Tilapia* in the islands of the South Pacific and Micronesia. Asian Fisheries Science 4:11-22.

Nelson, S. G. and D. Hopper. 1989. The freshwater fishes of Yap. University of Guam Marine Laboratory Technical Report No. 92:10-20.

Nelson, S. G., B. D. Smith, J. E. Parham, B. Tibbatts, and F. A. Camacho. 1995. A survey of the stream fishes of the upper reaches of the Ngermeskang River, Palau, with recommendations for conservation and monitoring. University of Guam Marine Laboratory Technical Report 100:1-31.

Nico, L. G. and P. L. Fuller. 1999. Spatial and temporal patterns of nonindigenous fish introductions in the United States. Fisheries 24:16-27.

Nico, L. G., H. L. Jelks, and T. Tuten. 2009. Non-native suckermouth armored catfishes in Florida: description of nest burrows and burrow colonies with assessment of shoreline conditions. Aquatic Nuisance Species Research Program Bulletin 9:1-30.

Nico, L. G. and S. J. Walsh. 2011. Nonindigenous freshwater fishes on tropical Pacific islands: a review of eradication efforts, Pages 91-101 *in* C. R. Veitch, M. N. Clout, and D. R. Towns (ed.), Islands invasives: eradication and management. International Union for Conservation of Nature, Gland, Switzerland.

Nico, L. G., J. D. Williams, and H. L. Jelks. 2005. Black carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society Special Publication 32, Bethesda, MD.

NISC (National Invasive Species Council). 2001. Meeting the invasive species challenge: national invasive species management plan. National Invasive Species Council, Washington D.C. *http://www.invasivespeciesinfo.gov/docs/council/mpfinal.pdf*.

NISC (National Invasive Species Council). 2008. 2008-2012 national invasive species management plan. National Invasive Species Council, Washington, D.C. *http://www.invasivespeciesinfo.gov/council/mp2008.pdf*.

NMC-CREES (Northern Marianas College Cooperative Research Extension and Education Service). 2011. Commonwealth of the Northern Mariana Islands aquaculture development plan: 2011-2015. Noumea, New Caledonia, 32 p.

NRC (National Resource Council). 2002. Predicting invasions of nonindigenous plants and plant pests. National Research Council; National Academy Press, Washington, D.C.

Nuov, S., H. Viseth, and O. Vibol. 2005. Present status of alien species in aquaculture and aquatic ecosystem in Cambodia, Pages 75-85 *in* D. M. Bartley, R. C. Bhujel, S. Funge-Smith, P. G. Olin, and M. J. Phillips (ed.), International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation. Xishuangbanna, People's Republic of China, 27-30 August 2003., FAO, Rome, Italy.

Orr, R. 2003. Generic nonindigenous aquatic organisms risk analysis review process, Pages 415-438 *in* R. G.M. and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.

Padilla, D. K. and S. L. Williams. 2004. Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. Frontiers in Ecology and the Environment 2:131-138.

Parenti, L. R. and J. A. Maciolek. 1993. New sicydiine gobies from Ponape and Palau, Micronesia, with comments on systematics of the subfamily Sicydiinae (Teleostei: Gobiidae). Bulletin of Marine Science 53:945-972.

Paulay, G. 1994. Biodiversity on oceanic islands: its origin and extinction. American Zoologist 34:134-144.

Paulay, G., R. Kropp, P. K. L. Ng, and L. G. Eldredge. 2003. The crustaceans and pycnogonids of the Mariana Islands. Micronesica 35-36:456-513.
Paulson, D. R. and D. W. Buden. 2003. The Odonata of Pohnpei, Eastern Caroline Islands, Micronesia. International Journal of Odonatology 6:39-64.
Perera, G. and J. G. Walls. 1996. Apple snails in the aquarium. T.F.H. Publications, Neptune City, NJ.
Perrings, C., K. Dehnen-Schmutz, J. Touza, and M. Williamson. 2005. How to manage biological invasions under globalization. Trends in Ecology and Evolution 20.
Peterson, A. T. 2003. Predicting the geography of species' invasions via ecological niche modeling. Quarterly Review of Biology 78:419-433.
Pheloung, P. C. 2003. An Australian perspective on the management of pathways for invasive species, Pages 249-269 *in* G. M. Ruiz and J. T. Carlton (ed.), Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57:239-251.
Pitt, W., D. Vice, and M. Pitzler. 2005. Challenges of invasive reptiles and amphibians. Pages 112-119 *in* Wildlife Damage Management Conferences Proceedings, University of Nebraska, Lincoln.
Prasad, R. 2003. Aquaculture potential in Fiji and other Pacific island countries. Micronesica 7:55-67.
Pyšek, P., V. Jarošík, P. E. Hulme, I. Kühn, J. Wild, M. Arianoutsou, S. Bacher, F. Chiron, V. Didžiulis, F. Essl, P. Genovesi, F. Gherardi, M. Hejda, S. Kark, P. W. Lambdon, M.-L. Desprez-Loustau, W. Nentwig, J. Pergl, K. Poboljšaj, W. Rabitsch, A. Roques, D. B. Roy, S. Shirley, W. Solarz, M. Vilà, and M. Winter. 2010. Disentangling the role of environmental and human pressures on biological invasions across Europe. Proceedings of the National Academy of Sciences 107:12157-12162.
Qiu, J.-W. and K.-L. Kwong. 2009. Effects of macrophytes on feeding and life-history traits of the invasive apple snail *Pomacea canaliculata*. Freshwater Biology 54:1720-1730.
R Development Core Team. 2004. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Rahel, F. J. 2002. Homogenization of freshwater faunas. Annual Review of Ecology and Systematics 33:291-315.
Randall, R. H., R. T. Tsuda, M. Gawel, R. Rechebei, and J. Chase. 1974. Field ecological survey of the Agana-Choat river basin. University of Guam Marine Laboratory Techincal Report No. 12:64.
Rawlings, T. A., K. A. Hayes, R. H. Cowie, and T. M. Collins. 2007. The identity, distribution, and impacts of non-native apple snails in the continental United States. BMC Evolutionary Biology 7 (Supplement 2):97-110.
RCS (Ramsar Convention Secretariat). 2006. The Ramsar convention manual: a guide to the convention on wetlands (Ramsar, Iran, 1971), 4th ed., Ramsar, Iran, 114 p.
Ribeiro, F., B. Elvira, M. J. Collares-Pereira, and P. B. Moyle. 2008. Life-history traits of non-native fishes in Iberian watersheds across several invasion stages: a first approach. Biological Invasions 10:89-102.
Ricciardi, A. and H. J. MacIsaac. 2000. Recent mass invasion of the North American Great Lakes by Ponto–Caspian species. Trends in Ecology and Evolution 15:62-65.
Ricciardi, A. and J. B. Rasmussen. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. Canadian Journal of Fisheries and

Aquatic Sciences 55:1759-1765.
Rixon, C. A. M., I. C. Duggan, N. M. N. Bergeron, A. Ricciardi, and H. J. Macisaac. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity and Conservation 14:1365–1381.
Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. World fishes important to North Americans: exclusive of species from continental waters of the United States and Canada. American Fisheries Society Special Publication 21, Bethesda, MD.
Rodda, G. H. F., Thomas H. and J. D. Reichel. 1991. The distributional patterns of reptiles and amphibians in the Mariana islands. Micronesica 24:195-210.
Roth, A., Jr. 1976. Preliminary checklist of the gastropods of Guam. University of Guam Marine Laboratory Technical Report No. 27:1-99.
Ruesink, J. L. 2005. Global analysis of factors affecting the outcome of freshwater fish introductions. Conservation Biology 19:1883-1893.
Ruesink, J. L., I. M. Parker, M. J. Groom, and P. M. Kareiva. 1995. Reducing the risks of nonindigenous species introductions. BioScience 45:465-477.
Ruiz, G. M. and J. T. Carlton, editors. 2003. Invasive species: vectors and management strategies. Island Press, Washington, DC.
Ryan, P. A. 1991. The success of the Gobiidae in tropical Pacific insular streams. New Zealand Journal of Zoology 18:25-30.
Sakuma, S. and P. Ueranant. 2007. Republic of Palau business opportunities report. Prepared for the U.S. Department of the Interior, Office of Insular Affairs, 32 p.
Sanger, H. and D. Hopper. 1989. Nutrient characteristics of the inland waters of Yap. University of Guam Marine Laboratory Technical Report No. 92:1-9.
Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American breeding bird survey. Auk 111:50-62.
Schreiner, I. and D. Nafus. 1989. Insects in the freshwater environments of Yap. University of Guam Marine Laboratory Technical Report No. 92:21-36.
Scott, D. A. 1993. Republic of Palau, Pages 285-298 *in* D. A. Scott (ed.), A directory of wetlands in Oceania. IWRB, Slimbridge, U.K. and AWB, Kuala Lumpur, Malaysia.
Siegrist, H. G., Jr. and R. H. Randall. 1992. Carbonate geology of Guam. p. 39 p. *in* Proceedings of the 7th International Coral Reef Symposium, Guam.
Simberloff, D. 1995. Why do introduced species appear to devastate islands more than mainland areas? Pacific Science 49:87-97.
Simberloff, D. 1998. Facing the future. World Conservation; quarterly bulletin of IUCN-the World Conservation Union 4/97-1/98:21-23.
Smith, B. D. 1989. A preliminary report on the freshwater gastropods of Yap, Caroline Islands. University of Guam Marine Laboratory Technical Report No. 92:70-78.
Smith, B. D. 2003. Prosobranch gastropods of Guam. Micronesica 35-36:244-270.
Smith, K. F., M. D. Behrens, L. M. Max, and P. Daszak. 2008. U.S. drowning in unidentified fishes: scope, implications, and regulation of live fish import. Conservation Letters 1:103-109.
Stafford, K. W., J. E. Mylroie, and J. W. Jenson. 2002. Karst geology and hydrology of Tinian and Rota (Luta), CNMI: a preliminary report. University of Guam, Water & Environmental Research Institute of the Western Pacific, Technical Report 96:1-25.

Steadman, D. W. 2006. Extinction and biogeography of tropical Pacific birds. University of Chicago Press, Chicago, IL.
Stinson, D. W. 1993. Commonwealth of the Northern Mariana Islands, Pages 225-241 *in* D. A. Scott (ed.), A directory of wetlands in Oceania. IWRB, Slimbridge, U.K. and AWB, Kuala Lumpur, Malaysia.
Taboroši, D. 2000. Karst inventory of Guam. University of Guam, Mangilao.
Taboroši, D., J. W. Jenson, and J. E. Mylroie. 2004. Karst features of Guam, Mariana Islands. Water and Environmental Reserach Institute of the Western Pacific, University of Guam, Technical Report 104.
Taboroši, D., J. W. Jenson, and J. E. Mylroie. 2005. Karst features of Guam, Mariana Islands. Micronesica 38:17-46.
Thum, R. A., A. T. Mercer, and D. J. Weisel. 2011. Loopholes in the regulation of invasive species: genetic identifications identify mislabeling of prohibited aquarium plants. Biological Invasions in press.
Tracey, J. Jr., S.O. Schlanger, J.T. Stark, D.B. Doan, and H.G. May. 1964. General geology of Guam. U.S. Geological Survey Professional Paper 403-A, 104 p.
Tucker, C. S. and J. A. Hargreaves, editors. 2008. Environmental best management practices for aquaculture. Wiley-Blackwell, Ames, IA.
USACE (U.S. Army Corps of Engineers). 1979. Ugum River draft interim report and environmental impact statement: harbors and rivers, Territory of Guam. Honolulu, HI, 346 p.
USDA-APHIS (U.S. Department of Agriculture, Animal and Plant Health Inspection Service). 2009. November 2009 unpublished trip report. Washington, D.C., 39 p.
USDA-APHIS (U.S. Department of Agriculture, Animal and Plant Health Inspection Service). 2010. Terrestrial plant and animal health risks associated with the U.S. military buildup in the Micronesian region. Washington, D.C., 602 p.
USFWS (U.S. Fish and Wildlife Service). 2010. U.S. Fish and Wildlife Service; Import and Export, Office of Law Enforcement, Pacific Region/Pacific Southwest Region. Last updated 10 August 2010; available at: *http://www.fws.gov/pacific/lawenforcement/importexport.html* (accessed January 2011). *http://www.fws.gov/pacific/lawenforcement/importexport.html*.
USFWS (U.S. Fish and Wildlife Service). 2011. Injurious wildlife species: listing the bighead carp (*Hypophthalmichthys nobilis*) as injurious fish: final rule. Federal Register, 15857-15858 p.
van der Brug, O. 1983a. Water resources of the Truk Islands. U.S. Geological Survey Water- Resources Investigations Report 82-4082, 223 p.
van der Brug, O. 1983b. Water resources of the Yap Islands. U.S. Geological Survey Water- Resources Investigations Report 82-357, 187 p.
van der Brug, O. 1984a. Water resources of Kosrae, Caroline Islands. U.S. Geological Survey Water-Resources Investigations Report 83-4161, 143 p.
van der Brug, O. 1984b. Water resources of Ponape, Caroline Islands. U.S. Geological Survey Water-Resources Investigations Report 83-4139, 171 p.
Van Dine, D. L. 1907. The introduction of top-minnows (natural enemies of mosquitoes) into the Hawaiian Islands. Hawaii Agriculture Experiment Station, Honolulu Press Bulletin 20:1-10.

Ward, P. E., S. H. Hoffard, and D. A. Davis. 1965. Hydrology of Guam. U.S. Geological Survey Professional Paper 403-H:28 p.

Wasson, K., D. Lohrer, M. Crawford, and S. Rumrill. 2002. Non-native species in our nation's estuaries: a framework for an invasion monitoring program. National Estuarine Research Reserve Technical Report Series 2002:1:1-57.

Watson, R. E. 1992. A review of the gobiid fish genus *Awaous* from insular streams of the Pacific Plate. Ichthyological Exploration of Freshwaters 3:161-176.

Welcomme, R. L. 1981. Register of international transfers of inland fish species. FAO Fisheries Technical Paper No. 213:120.

Welcomme, R. L. 1988. International introductions of inland aquatic species. Food and Agricultural Organization of the United Nations.

WERI (Water and Environmental Research Institute of the Western Pacific), 2011, Natural resource atlas of southern Guam. *http://www.hydroguam.net/watersheds-overview.php*. (Accessed July 2011).

Williamson, M. and A. Fitter. 1996. The varying success of invaders. Ecology and Society 77:1661-1666.

Wilson, J. R. U., E. E. Dormontt, P. J. Prentis, A. J. Lowe, and D. M. Richardson. 2009. Something in the way you move: dispersal pathways affect invasion success. Trends in Ecology and Evolution 24:136-144.

Win, U. H. 2005. Alien species in Myanmar, *in* D. M. Bartley, R. C. Bhujel, S. Funge-Smith, P. G. Olin, and M. J. Phillips (ed.), International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation. Xishuangbanna, People’s Republic of China, 27-30 August 2003., FAO, Rome, Italy.

Winter, S. J. 1993. Federated States of Micronesia water resources studies bibliography. Water and Energy Research Institute of the Western Pacific, University of Guam, Technical Report 74.

Wittenberg, R. and M. J. W. Cock, editors. 2001. Invasive alien species: a toolkit of best prevention and management practices. CAB International, Wallingford, Oxon, UK.

Wowor, D. and P. K. L. Ng. 2007. The giant freshwater prawns of the *Macrobrachium rosenbergii* species group (Crustacea: Decapoda: Caridea: Palaemonidae). The Raffles Bulletin of Zoology 55:321-336.

Yamamoto, M. N. and A. W. Tagawa. 2000. Hawai'i's native and exotic freshwater animals. Mutual Publishing, Honolulu, HI.

Yeung, C. W. 2005. Rainfall-runoff and water-balance models for management of the Fena Valley Reservoir, Guam. U.S. Geological Survey Scientific Investigations Report 2004-5287:52 p.

Zabin, C.J., G.M. Ruiz, M. Minton, G. Ashton, I. Davidson, C. Hewitt, M. Campbell, L.G. Eldredge, G. Smith, and P.W. Fofonoff. 2011. Risk analysis for marine invasive species and biosecurity plan for Guam and the Micronesian region. Smithsonian Institution, in prep. p.

Zipkin, E. F., C. E. Kraft, E. G. Cooch, and P. J. Sullivan. 2009. When can efforts to control nuisance and invasive species backfire? Ecological Applications 19:1585-1595.

# Appendixes

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-1. Agana Spring, Guam, January 2010. Site of introduction of several non-native freshwater species. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-2. Inajaran River, Guam, January 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-3. USGS and DAWR biologists sampling for freshwater fishes and macroinvertebrates in the Moulap River, Guam, March 2010. Photograph by W.J. Barichivich.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-4. Fena Reservoir, Guam, March 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-5. USGS biologists sampling for freshwater fishes at Fena Reservoir spillway, Guam, March 2010. Photograph by W.J. Barichivich.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-6. L.G. Nico with non-native *Clarias sp.* captured at Fena Reservoir spillway, March 2010. Photograph by W.J. Barichivich.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-7. Masso Reservoir restoration, Guam, March 2010. DAWR-sponsored project to remove non-native species and establish recreational fishing facility for native species. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-8. DAWR biologist B. Tibbatts assists USGS biologists in sampling for non-native poeciliid fishes at Lost Pond, northern Guam, March 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-9. Lake Susupe, Saipan, January 2010. Site of introduction of several non-native freshwater species. Photograph by S.J. Walsh.

Figure 1-10. "Costco Marsh," Saipan, January 2010. Wetland site where non-native tilapia were introduced. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

throughout Micronesia. Photograph by S.J. Walsh.

Figure 1-11. Amplexing pair of cane toads *(Rhine/fa marina)* found on Saipan; an abundant and widespread non-native anuran found

throughout Micronesia. Photograph by S.J. Walsh.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.


Figure 1-12. Tilapia (*Oreochromis niloticus*) hybrids obtained live from food market on Guam, 4 April 2010. Photograph by L.G. Nico.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-13. Fresh tilapia for sale at Saturday morning flea market, Dededo, Guam, January 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-14. Live *Clarias batrachus* for sale at Saturday morning flea market, Dededo, Guam, January 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-15. Hybrid tilapia produced at Northern Marianas College Cooperative Research Extension and Education Service. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.


Figure 1-16. Entrance to Northern Marianas College Cooperative Research Extension and Education Service aquaculture facility. The NMC-CREES implements strong biosecurity measures. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.


Figure 1-17. Entrance to Guam Aquaculture DevelopmentTraining Center (Fadian Hatchery), University of Guam. The GADTC implements strong biosecurity measures. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-18. Hatchery raceways at the Guam Aquaculture Development and Training Center. Photograph by S.J. Walsh.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-19. Tilapia in hatchery raceway of Guam Aquaculture Development and Training Center. Photograph by S.J. Walsh.

Figure 1-20. Effluent of the Guam Aquaculture Development and Training Center; all water passing through the hatchery is discharged onto open rock and then directly to the ocean. Photograph by S.J. Walsh.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.


Figure 1-21. Live aquarium fish for sale at retail pet shop in Barrigada, Guam, March 2010. Photograph by L.G. Nico.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-22. Rock quarry on Malakal Island, Palau. Site of introduced tilapia where eradication efforts were unsuccessful as of March 2010. Photograph by W.J. Barichivich.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-23. Lake Ngardok, Babeldaob Island, Palau, March 2010. Largest natural lake in Micronesia and site of introduced poeciliids *(Xiphophorus macu/atus).* Photograph by R.A. Englund.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-24. Ngerimel Reservoir, Babeldaob Island, Palau. Source of municipal water supply for Koror. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-25. Water-garden pond at Belau National Museum, Koror, Palau. Site of introduced guppies *(Poeci/ia reticulata)* and cane toads *(Rhine/fa marina),* March 2010. Photograph by S.J. Walsh.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-26. Giant clam culture facilities at the Palau Mariculture Demonstration Center on Malakal Island, Palau, March 2010. Photograph by S.J. Walsh.

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-27. USGS biologists sampling fishes and macroinvertebrates from streams of Babeldaob Island, Palau, March 2010. Photograph by W.J. Barichivich.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-28. Tributary of Nanpii-Kiepw River, Pohnpei, Federated States of Micronesia, April 2010. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-29. Native gobies *(Stiphodon caeruleus)* spawning on rocks in a stream on Pohnpei, Federated States of Micronesia, April 2010. Amphidromous gobies are the most abundant fishes in Micronesian streams and exhibit high endemism. Photograph by S.J. Walsh.

**Appendix 1.** Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-30. College of Micronesia biologist B. Lynch snorkeling to observe native fishes in streams on Pohnpei, Federated States of Micronesia, April 2010. Photograph by S.J. Walsh

**Appendix 1**. Representative freshwater habitats and freshwater species of Micronesia.

Figure 1-31. Setting small trap to capture non-native poeciliids at Lake Ngardok, Republic of Palau, April 2010. Photograph by L.G. Nico

Figure 1-32. Waterfalls are natural barriers that restrict upstream dispersal of many native and non-native fishes and other aquatic animals. Babeldaob Island, Palau, March 2010. Photograph by L.G. Nico

**Appendix 2.** Data matrix used in frequentist models for risk assessment of establishment success for non-native inland fishes of Hawaii and Guam. [HS, status in Hawaii; GS, status in Guam (0 = introduced, not established; 1 = established). Variable codes correspond to Table 22]

| Dependent variable | | Taxon | Independent variable | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **HS** | **GS** | | **1** | **2** | **3.1** | **3.2** | **3.3** | **3.4** | **3.5** | **3.6** | **3.7** | **3.8** | **3.9** | **3.10** | **3.11** | **3.12** | **Sum** | **5** | **7** | **9** | **10** | **11** | **12** | **13** | **14** |
| 0 | | *Osteoglossum bicirrhosum* ? | Osteoglossidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 7 | 3 | 4 | 3 | 1 | 2 | 6 |
| | 0 | *Anguilla japonica* | Anguillidae | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 | 4 | 6 | 1 | 3 | 5 | 3 | 2 | 10 |
| 0 | | *Anguilla marmorata* | Anguillidae | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 | 4 | 7 | 1 | 3 | 5 | 3 | 2 | 10 |
| | 0 | *Anguilla rostrata* | Anguillidae | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 | 4 | 6 | 1 | 3 | 5 | 3 | 2 | 10 |
| 1 | | *Dorosoma petenense* | Clupeidae | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 2 | 3 | 1 | 5 | 4 | 2 | 1 | 7 |
| 1 | | *Carassius auratus* | Cyprinidae | 12 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 7 | 3 | 4 | 1 | 2 | 1 | 2 | 2 | 5 |
| 0 | 0 | *Ctenopharyngodon idella* | Cyprinidae | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 5 | 4 | 2 | 1 | 1 | 1 | 2 | 2 | 5 |
| 1 | 1 | *Cyprinus carpio* | Cyprinidae | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 8 | 4 | 4 | 1 | 5 | 1 | 2 | 2 | 5 |
| | 0 | *Hypophthalmichthys nobilis* | Cyprinidae | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 7 | 4 | 3 | 1 | 1 | 4 | 1 | 2 | 7 |
| 1 | | *Puntius filamentosus* | Cyprinidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 5 | 1 | 1 | 5 | 2 | 1 | 8 |
| | 0 | *Puntius lateristriga* | Cyprinidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 1 | 1 | 5 | 1 | 1 | 7 |
| 1 | | *Puntius semifasciolatus* | Cyprinidae | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 1 | 1 | 2 | 1 | 1 | 4 |
| 1 | | *Misgurnus anguillicaudatus* | Cobitidae | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 5 | 2 | 4 | 1 | 4 | 4 | 1 | 3 | 8 |
| 0 | | *Leporinus fasciatus* | Anostomidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 2 | 1 | 3 | 1 | 1 | 5 |
| 0 | | *Colossoma macropomum* ? | Characidae | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 4 | 2 | 1 | 4 | 3 | 1 | 2 | 6 |
| 0 | | *Pygocentrus nattereri* | Characidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 7 | 2 | 4 | 3 | 1 | 1 | 5 |
| 0 | | *Ameiurus nebulosus* | Ictaluridae | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 | 2 | 4 | 4 | 2 | 2 | 8 |
| 1 | 0 | *Ictalurus punctatus* | Ictaluridae | 3 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 5 | 4 | 4 | 2 | 4 | 4 | 2 | 1 | 7 |
| | 0 | *Pangasianodon hypophthalmus* | Pangasiidae | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 1 | 4 | 5 | 1 | 3 | 9 |
| | 1 | *Clarias batrachus* | Clariidae | 3 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 3 | 4 | 2 | 5 | 5 | 2 | 3 | 10 |
| 1 | | *Clarias fuscus* | Clariidae | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 2 | 6 | 2 | 2 | 5 | 1 | 3 | 9 |
| | 1 | *Clarias macrocephalus* | Clariidae | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 4 | 6 | 2 | 5 | 5 | 2 | 3 | 10 |
| | 0 | *Arius* sp. | Ariidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 6 | 3 | 3 | 5 | 3 | 1 | 9 |
| 0 | | *Synodontis* sp. | Mochokidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 1 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Corydoras aeneus* ? | Callichthyidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 1 | 4 | 3 | 1 | 3 | 7 |
| 1 | | *Ancistrus cf. temminckii* | Loricariidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 3 | 7 |

**Appendix 2.** Data matrix used in frequentist models for risk assessment of establishment success for non-native inland fishes of Hawaii and Guam. [HS, status in Hawaii; GS, status in Guam (0 = introduced, not established; 1 = established). Variable codes correspond to Table 22]

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | *Hypostomus cf. watwata* | Loricariidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 2 | 4 | 3 | 2 | 3 | 8 |
| 0 | | *Peckoltia* sp. | Loricariidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Pterygoplichthys multiradiatus* | Loricariidae | 6 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 2 | 4 | 3 | 1 | 3 | 7 |
| 0 | | *Plecoglossus altivelis* | Plecoglossidae | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 4 | 1 | 1 | 4 | 3 | 1 | 8 |
| 1 | | *Oncorhynchus mykiss* | Salmonidae | 5 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 6 | 1 | 1 | 1 | 3 | 1 | 5 |
| 0 | | *Oncorhynchus tshawytscha* | Salmonidae | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 6 | 1 | 1 | 1 | 3 | 1 | 5 |
| 0 | | *Salmo trutta* | Salmonidae | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 1 | 1 | 1 | 3 | 1 | 5 |
| 0 | | *Salvelinus fontinalis* | Salmonidae | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 6 | 1 | 1 | 1 | 2 | 1 | 4 |
| 0 | | *Aplocheilus lineatus* | Aplocheilidae | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 6 |
| 0 | | *Nothobranchius guentheri* | Nothobranchiidae | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 5 | 1 | 5 | 3 | 1 | 2 | 6 |
| 0 | | *Fundulus grandis* | Fundulidae | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 1 | 3 | 2 | 3 | 2 | 7 |
| 1 | 1 | *Gambusia affinis* | Poeciliidae | 23 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 5 | 3 | 4 | 1 | 2 | 2 | 5 |
| 1 | | *Limia vittata* | Poeciliidae | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 3 | 4 | 2 | 2 | 2 | 6 |
| 1 | 1 | *Poecilia latipinna* | Poeciliidae | 5 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 3 | 5 | 2 | 3 | 2 | 7 |
| 1 | | *Poecilia mexicana/sphenops complex* | Poeciliidae | 6 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 3 | 5 | 5 | 2 | 2 | 9 |
| 1 | 1 | *Poecilia reticulata* | Poeciliidae | 30 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 3 | 4 | 3 | 2 | 2 | 7 |
| 1 | 1 | *Xiphophorus hellerii* | Poeciliidae | 15 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 4 | 3 | 4 | 3 | 1 | 2 | 6 |
| 1 | 0 | *Xiphophorus maculatus* | Poeciliidae | 11 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 3 | 4 | 3 | 1 | 2 | 6 |
| 0 | | *Xiphophorus variatus* | Poeciliidae | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 3 | 4 | 3 | 1 | 2 | 6 |
| 0 | | *Oryzias latipes* | Adrianichthyidae | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 5 | 3 | 5 | 2 | 2 | 2 | 6 |
| 1 | | *Xenentodon cancila* | Belonidae | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 1 | 5 | 5 | 3 | 2 | 10 |
| 1 | | *Monopterus albus ?* | Synbranchidae | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 5 | 4 | 6 | 2 | 4 | 5 | 2 | 3 | 10 |
| | 0 | *Lates calcarifer* | Centropomidae | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 4 | 6 | 1 | 3 | 5 | 3 | 2 | 10 |
| 0 | | *Morone saxatilis* | Moronidae | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 5 | 4 | 7 | 1 | 1 | 4 | 3 | 1 | 8 |
| 0 | | *Kuhlia rupestris* | Kuhlidae | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 | 1 | 3 | 5 | 3 | 1 | 9 |
| 1 | | *Lepomis cyanellus* | Centrarchidae | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4 | 3 | 5 | 2 | 2 | 1 | 1 | 2 | 4 |
| 1 | | *Lepomis macrochirus* | Centrarchidae | 6 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 5 | 2 | 2 | 4 | 1 | 2 | 7 |
| 1 | 0 | *Micropterus dolomieu* | Centrarchidae | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 7 | 2 | 1 | 1 | 1 | 1 | 3 |

**Appendix 2.** Data matrix used in frequentist models for risk assessment of establishment success for non-native inland fishes of Hawaii and Guam. [HS, status in Hawaii; GS, status in Guam (0 = introduced, not established; 1 = established). Variable codes correspond to Table 22]

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | *Micropterus salmoides* | Centrarchidae | 10 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 3 | 7 | 2 | 4 | 4 | 2 | 2 | 8 |
| 1 | | *Lutjanus fulvus* | Lutjanidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 1 | 3 | 5 | 3 | 1 | 9 |
| 1 | | *Amatitlania nigrofasciata* | Cichlidae | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 2 | 1 | 3 | 1 | 2 | 6 |
| 1 | | *Amphilophus citrinellus* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 2 | 3 | 1 | 2 | 6 |
| 0 | | *Amphilophus labiatus* | Cichlidae | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | 1 | *Astronotus ocellatus* | Cichlidae | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 6 | 2 | 2 | 3 | 1 | 2 | 6 |
| 1 | 1 | *Cichla ocellaris* ? | Cichlidae | 4 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 7 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Cryptoheros spilurus* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Hemichromis elongatus* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 6 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Hypsophrys nicaraguensis* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Melanochromis johannii* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 3 | 2 | 3 | 1 | 2 | 6 |
| 1 | | *Oreochromis macrochir* | Cichlidae | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 4 | 3 | 1 | 3 | 4 | 3 | 1 | 2 | 6 |
| 1 | 1 | *Oreochromis mossambicus* | Cichlidae | 43 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 8 | 3 | 4 | 3 | 5 | 3 | 2 | 2 | 7 |
| 1 | | *Parachromis managuensis* | Cichlidae | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 6 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Pelvicachromis pulcher* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 5 | 2 | 4 | 3 | 2 | 2 | 7 |
| 0 | | *Pterophyllum* sp. | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 6 | 2 | 2 | 3 | 1 | 2 | 6 |
| 1 | | *Sarotherodon melanotheron* | Cichlidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 3 | 5 | 3 | 2 | 2 | 7 |
| 1 | | *Thorichthys meeki* | Cichlidae | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 4 | 3 | 1 | 2 | 6 |
| 1 | | *Tilapia rendalli* | Cichlidae | 8 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 6 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 7 |
| 1 | 1 | *Tilapia zillii* | Cichlidae | 7 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 3 | 2 | 2 | 5 | 3 | 2 | 2 | 7 |
| 1 | | *Omobranchus ferox* | Blenniidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 4 | 2 | 3 | 3 | 3 | 1 | 7 |
| 1 | | *Mugilogobius cavifrons* | Gobiidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 6 | 2 | 3 | 3 | 3 | 1 | 7 |
| | 1 | *Betta pugnax* | Osphronemidae | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 5 | 3 | 1 | 3 | 1 | 3 | 7 |
| 0 | | *Osphronemus goramy* | Osphronemidae | 7 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 3 | 4 | 2 | 2 | 3 | 2 | 3 | 8 |
| 0 | | *Trichopodus leerii* | Osphronemidae | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 2 | 3 | 1 | 3 | 7 |
| 1 | 1 | *Channa maculata/striata* | Channidae | 7 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 3 | 7 | 2 | 2 | 5 | 1 | 3 | 9 |

# Freshwater Risk Assessment:
# Invasive Aquatic Plant Overview

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## Tables

## Figures

# 1. Introduction

The purpose of this document is to guide the Department of Defense (DoD), as well as civilian government and non-governmental organizations working within the region, in identifying risk associated with the potential introduction of freshwater invasive alien plant species (IAPS) in Hawaii and Micronesia. It is one component of a larger effort to address all invasive species issues in that region. The intent of this component of the Micronesia Biosecurity Plan or MBP is to provide guidance to countries and territories in the region on how to protect their natural resources and economies from freshwater IAPS by recommending management actions that will 1) reduce the risks for new introductions 2) provide early warning of new introductions and 3) minimize the spread of new infestations and 4) control, or if possible, eradicate infestations.

This effort is necessary due to the U.S. Military relocation to Guam and Commonwealth of the Northern Mariana Islands (CNMI) (the Buildup) and the associated Environmental Impact Statement (DoN 2010). The planned Buildup activities will increase the risk for IAPS and other invasive species through increased movement and trade within and outside the region and increased habitat disturbance (DoN 2010). The Buildup as envisioned in 2009 would involve the relocation of approximately 8,600 U. S. Marine Corps forces and their approximate 9,000 dependents from Okinawa, Japan to Guam; the development of existing and construction of new infrastructure and facilities to support these Marines; the construction of a new wharf and infrastructure in Apra Harbor (Guam) to support transient nuclear powered aircraft carriers; and the relocation of approximately 600 U.S. Army personnel and their approximately 900 dependents to establish and operate an Air Missile Defense Task Force in Guam (DoN 2010). DoD expected a total of approximately 30,000 people, including active duty members, civilian personnel, and dependents of both to relocate to Guam as a result of the Buildup. At the peak of construction, DoD projected the population of Guam would increase by as much as 80,000 people due to the associated military and construction work related to the Buildup. Since 2010 the overall size of the Buildup has been in question and it is no longer clear exactly how many troops, civilian and transitory workers will be required.

Regardless of its ultimate size, the Buildup will have an indirect impact beyond Guam and CNMI, the geographic scope also includes the Republic of Palau (Palau), the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), and Hawai'i (hereafter referred to as the Region) (Figure 1-1).

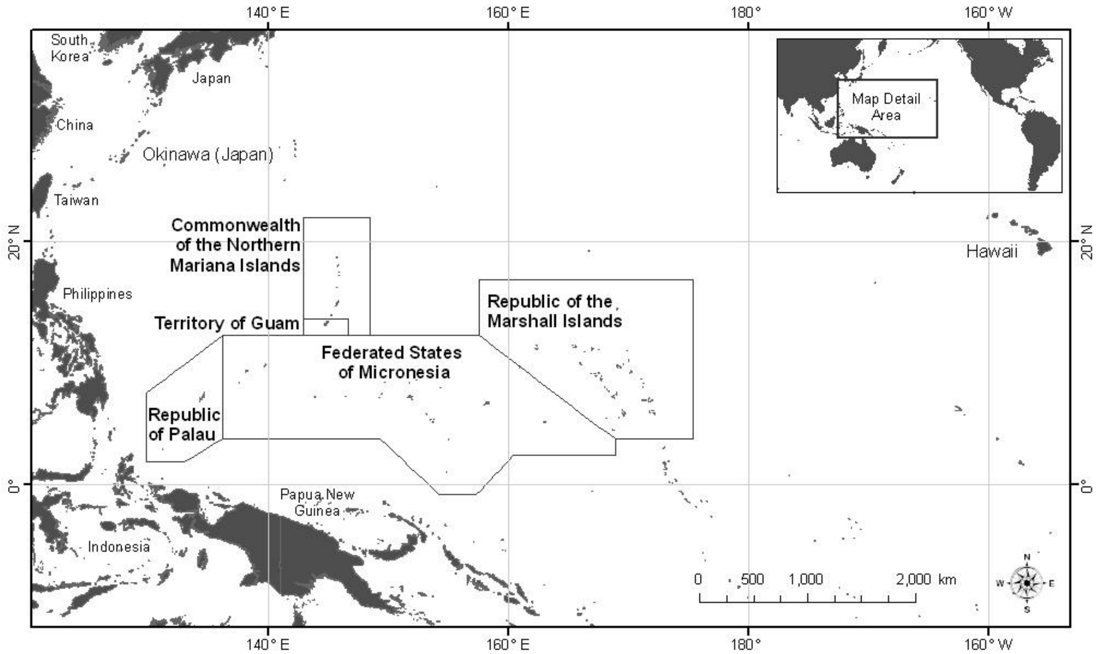


**Figure 1-1: Geographic scope of the MBP Region.**

## 1.1 Impacts of IAPS on Freshwater Habitats

Establishment and spread of IAPS in freshwater habitats often leads to considerable ecological, economical, and cultural harm. IAPS can reduce species richness and abundance of native plants (Boylen et al. 1999), affect utilization of drinking water supplies (Newroth 1985), increase water loss through evapotranspiration (Boyd 1987), retard water flow (Carpenter and Lodge 1986), and disrupt hydropower generation. IAPS can consume large amounts of oxygen during rapid senescence (Godshalk et al. 1977) creating fish kills, decrease land values (Halstead et al. 2003, Rockwell 2003), and diminish recreational opportunities such as boating, waterskiing, and fishing (Van Nes et al. 1999). Toxigenic blue-green algae associated with IAPS have been implicated in bird mortality (Wilde et al. 2005) and have the potential to affect human health. Conservative estimates of annual costs associated with IAPS in the United States (U.S.) are $10 million in losses and damages and $100 million in control (Pimentel et al. 2005). Flood control and recreation benefits associated with IAPS control in the U.S. are estimated to be over ten times higher (Rockwell 2003). Although IAPS can be dispersed by natural water currents, wind patterns, and animal movements; anthropogenic factors have substantially increased the rate and geographic range of invasions (Muirhead et al. 2009). In particular, increased globalization of trade has been correlated with higher rates of biological invasions (Levine and D'Antonio 2003) and establishment success is often greater in disturbed habitats (Chytrý et al. 2008).

## 1.2 The Freshwater IAPS Invasion Process

Although the islands in the Micronesia region are relatively isolated, they are susceptible to IAPS introduction. In fact, the low native freshwater aquatic plant species richness on the islands (there are only three native submersed species) may make the freshwater habitats on the islands particularly vulnerable to IAPS due to the available “niche space” for invaders (Kueffer et al. 2010). This available “niche space” is just one of many factors that determines whether an IAPS will successfully invade an ecosystem after introduction. Catford et al. (2008) provides a useful framework for describing the components or factors in the invasion process (Figure 1-2). These components which are summarized below include the transport and introduction to an ecosystem followed by interactions between IAPS propagule pressure, abiotic characteristics of the ecosystem, and biotic characteristics of the IAPS and invaded community.

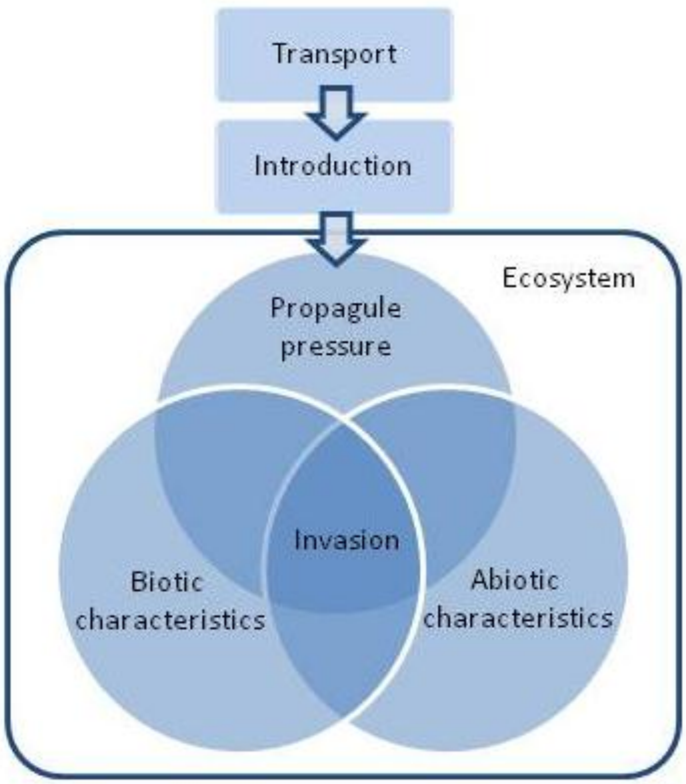


**Figure 1-2: Schematic of how the transport and introduction of IAPS to an ecosystem influences propagule pressure; and how propagule pressure, abiotic characteristics, and biotic characteristics interact to determine invasion success (adapted from (Catford et al. 2008)).**

IAPS are transported to new regions through natural pathways such as wind and water currents, and anthropogenic pathways such as ballast water or the pet and aquarium trade. The likely pathways of freshwater IAPS invasions to the Region are described below in Section 2. Once transported to a new region, IAPS can be released to the environment by accident or intent.

Once an IAPS is released to the environment, propagule pressure, the number of individuals released during an event and the frequency of events, are key characteristics in determining invasion success. Although a single individual can lead to successful invasion for some IAPS, higher propagule pressure is important for the continued invasion success of most IAPS.

The abiotic characteristics of an environment can also determine which IAPS successfully invade. The abiotic characteristics of freshwater aquatic environments include temperature, salinity, nutrient concentrations, light availability, soils, water flow, water depth, and the seasonality of water levels. In addition, disturbance of environments by both natural and anthropogenic means can also promote invasion success. Characteristics of the Region's invasible freshwater aquatic habitats are described in Section 4.

Biotic characteristics of the IAPS and the native species also influence invasion success. Some of these biotic characteristics include a species competitive ability, dispersal modes, and reproductive capacity. The biotic characteristics of the Region's potential invaders are included in the Aquatic Weed Risk Assessment (Appendix B) and are summarized in Section 3.

## 2. Micronesia Region Invasion Pathways

Geographic isolation of islands is thought to limit the natural transport of viable freshwater and other IAPS via pathways such as wind patterns, water currents and animals (MacArthur and Wilson 1967). The islands of Micronesia are indeed isolated (Table 2-1); however, in a study of island plant invasions at a global scale, (Kueffer et al. 2010) found that human development (measured as gross domestic product) and habitat diversity are much more important factors than geographic isolation in determining the number of IAPS present. Kueffer et al. (2010) noted that human activity is the most important invasion pathway and that most IAPS were introduced intentionally.

**Table 2-1: Approximate statute miles between locales.**

| | Tokyo, JP | Hagåtña, Guam | Honolulu, HI | Sydney, NSW | Los Angeles, CA |
|---|---|---|---|---|---|
| Saipan, CNMI | 1460 | 136 | 3711 | 3393 | 5976 |
| Palikir, FSM | 2301 | 1018 | 3099 | 2842 | 5590 |
| Hagåtña, Guam | 1561 | 0 | 3809 | 3283 | 6099 |
| Ngerulmud, Palau | 1966 | 802 | 4592 | 3046 | 6898 |
| Majuro, RMI | 2799 | 1850 | 2285 | 3110 | 4834 |

### 2.1 Aquarium and Pet Trade

The aquarium plant trade is an important pathway for the spread and introduction of invasive species (Keller and Lodge 2007; Strecker et al. 2011) and is the primary driver of biosecurity risks associated with electronic commerce (Derraik and Phillips 2010). The aquarium trade is responsible for the introduction of several freshwater IAPS into the U.S., including Eurasian water milfoil (*Myriophyllum spicatum*), giant salvinia (*Salvinia molesta*), and Brazilian egeria (*Egeria densa*) (Reichard and White 2001). Many aquarium enthusiasts purchase fresh plant material for their aquaria online. The growing use and increasing speed and efficiency of postal/shipping delivery increases the probability that healthy invasive plants will reach appropriate climates for establishment and invasion (Reichard and White 2001).

Species misidentification, “hitchhiking” species, and disregard for regulations are major concerns with the aquarium and pet trade. Maki and Galatowitsch (2004) found that 93% of pond-plant shipments contained plant or animal species that were not ordered, and that 100% of shipments were contaminated with plants that were not ordered. Aquarium and pet trade vendors fulfilled 13 of 14 orders for species that were prohibited by either U.S. federal or state regulations, demonstrating that ignorance of or disregard for rules and regulations for the plant trade is commonplace (Maki and Galatowitsch 2004).

Nine of the first ten freshwater aquatic plant distributors returned by a U.S. internet search conducted by us during 2010 were U.S. companies. Seven of these top ten internet vendors made no mention of regulations pertaining to live plant transport. One vendor indicated that they verified the legality of shipping a plant to the customer, and two indicated that they placed the responsibility for determining the legality of the shipment on the customer.

After aquarium and water gardening species are imported, they are often discarded to ponds, ditches, streams, and lakes (Kay and Hoyle 2001; Maki and Galatowitsch 2004). Risks posed by the aquarium trade can be reduced through education regarding the dangers of improper disposal of aquarium plants (Cohen et al. 2007). Use of scientific rather than common names of plant species (Kay and Hoyle 2001; Keller and Lodge 2007), and regulation of the intentional sale and transport of prohibited species will reduce the risk of IAPS introduction (Maki and Galatowitsch 2004).

Shipments of IAPS are likely to go undetected by both USPS and USCBP under current management practices due to U.S. Federal regulations, the large number of vendors, and discrete labeling. U.S. domestic mail is protected by being sealed against inspection (Title 39, United States Code, Section 404(c)); therefore, a U.S. Federal Search Warrant is required to open domestic mail including letters, packages, Express Mail packages and envelopes, and U.S. Priority Mail packages and envelopes. Domestic mail to Guam and the CNMI passes first through Honolulu, Hawai'i, but its inspection is not part of the Hawai'i Plant Protection and Quarantine pre-departure inspection program (D. Berringer, APHIS-PPQ, pers. comm.). All Domestic mail shipped to Guam through Honolulu is subject to an agricultural inspection in Honolulu, however, data on the number of parcels subjected to inspection was unavailable to us.

## 2.2 Ornamental Aquatic Plant Trade

The ornamental aquatic plant trade includes a diverse array of plants that are easy to grow, require minimal maintenance, and reproduce quickly (Bell et al. 2003, Peters et al. 2006) – all characteristics of successful invasive plants. In a global study of IAPS in island habitats, Kueffer et al. (2010) found that half of IAPS are ornamental plants. Ornamental ponds and water features are common within hotel, resort, and casino landscaping in Micronesia. Some hotels propagate and grow their own nursery stock on site for use in landscape features. Risks associated with these features include the distribution of plant propagules during flooding events or typhoons, distribution by birds, and intentional dispersal by staff, guests and other island residents.

## 2.3 Medicinal and Culinary Aquatic Plant Trade

Temporary and permanent workers from a diverse range of cultures, including the Philippines, China, and Korea are expected to constitute a large proportion of the work force associated with the Buildup (DoN 2010). These workers could bring along their culinary and medicinal cultures which may include freshwater IAPS. *Ipomoea aquatica* (water spinach) is a notable example of an IAPS introduced as a vegetable that is currently widespread and consumed throughout the region. Up to 80% of the populations in some Asian and African countries depend on traditional medicine for their primary health care (WHO 2003). The aquatic plant *Monochoria vaginalis* is traditionally used in the Indian State of Tamil Nadu to treat toothaches and as a dentifrice (Ganesan 2008). Alang-ilang (*Cananga odorata*) is a Tongan herbal medicine which has naturalized on numerous Pacific islands (PIER 2010). Weedy species may serve dual purposes; acapulco (*Senna alata*) is a ringworm treatment and is also occasionally planted to improve taro fields (PIER 2010).

## 2.4 Tourism and Business Travel

Tourism accounts for 40 to 90% of the visits to some Micronesian islands (Table 2-2Table 2-1). Risks associated with tourism include movement of passenger cargo and the unintentional introduction of plant material stuck to vessels or vehicles. Between 1984 and 2000, 62% of the 725,000 plant-pest interceptions recorded by USDA APHIS were associated with passenger baggage. Most interceptions were at airports (73%), followed by interception during land based border crossing (13%), and finally interception at marine ports (9%). Seven percent of the interceptions were weed species (McCullough et al. 2006).

**Table 2-2: Visitors that declared "tourism" as reason for visit to FSM, RMI, and Palau. No data available for CNMI.**

| | FSM | RMI | Palau |
|---|---|---|---|
| Year of survey | 2006 | 2005 | 2006 |
| Total visitors | 19,136 | 9,173 | 87,206 |
| Tourism | 13,345 | 3,658 | 78,252 |
| % of total | 70 | 40 | 90 |
| Country of residence of tourists (% of total) | U.S. (43)<br>Japan (20)<br>Europe (16) | U.S. (28)<br>Other Pacific Islands (22)<br>Japan (17) | Japan (35)<br>Taiwan (17)<br>Korea (16) |

Source: Federated States of Micronesia Division of Statistics, Republic of Palau Office of Planning and Statistics, Republic of the Marshall Islands Planning and Statistics Office.

## 2.5 Movement of DoD Equipment and Personnel

Unintentional movement of IAPS may occur when plant propagules (vegetative fragments, seeds, capsules, roots, etc.), including those of aquatic plant species, adhere to equipment, hulls of boats, and in standing water moved from site to site. There is a risk that the relocation of equipment to Micronesia and routine deployment and training activities could increase the potential for accidental movement of plant propagules. It is worth noting that Cofrancesco et al. (2007) did reviewed some of the existing guidelines for inspecting and sterilizing military equipment from invasive species.

## 2.6 Movement of Cargo

Cargo is imported and exported from Guam by several methods including surface shipping containers, break-bulk (cargo packed in cases, bales, cartons, etc.), roll on-roll off (vehicles), barges, fishing vessels, private yachts and air transport. The vast majority of the cargo imported and exported from Guam (over 97% by weight) has been transported via surface shipping methods rather than via air transport (Table 2-3).

During the Buildup, the original number of commercial cargo containers handled by the Port Authority of Guam was expected to increase by about 25% between 2008 and 2018 while the number of military containers will increase to a peak of about 400% above 2008 levels (currently it is difficult to say how realistic these figures remain as the Buildup planning is under consideration and may change significantly before the efforts are completed). Following the Buildup the number of military containers could stabilize at approximately 38,000 per year until at least 2027 (DoN 2010) (again at this time more updated and realistic numbers are not known and will depend on the final true make-up of the proposed DoD Buildup). Break-bulk cargo shipments to Guam are projected to follow a similar trend to container shipments, but peak several years earlier.

**Table 2-3: Guam surface and air cargo imports and exports from 2006 to 2009.**

| Movement type | 2009 | 2008 | 2007 | 2006 |
|---|---|---|---|---|
| Surface cargo (revenue tons[a])[b] | | | | |
| *Unloaded (Import)* | 1,213,400 | 1,269,600 | 1,226,300 | 1,139,200 |
| *Loaded (Export)* | 194,700 | 213,700 | 213,500 | 194,900 |
| *Transship* | 447,700 | 576,500 | 629,000 | 579,800 |
| *Total surface cargo* | 1,855,800 | 2,059,800 | 2,068,800 | 1,913,900 |
| Air cargo (metric tons)[c] | | | | |
| *Unloaded (Import)* | 16.539 | 17,528 | 15,380 | 16,904 |
| *Loaded (Export)* | 9,046 | 11,616 | 12,998 | 15,022 |
| *Total air cargo* | 25,585 | 29,144 | 28,378 | 31,926 |

[a]Revenue tons are equal to either metric tons or cubic meters depending on cargo type. [b]Source: Port Authority of Guam and the Guam International Airport Authority, Government of Guam. [c]Source: Guam International Airport Authority, Government of Guam

All DoD air cargo is received at Andersen Air Force Base and all DoD surface cargo is received at the Naval Base Guam. Household goods associated with military personnel constitute the largest volume of cargo moving on and off of Guam (D. Vice, USDA Wildlife Services, pers. comm.). When military personnel undergo a permanent change of station their household personal goods can be shipped via air or surface. Plant propagules can lodge in tires of vehicles, in equipment, or they can adhere to hulls of boats, kayaks, personal watercraft, or other watercraft. The risk of IAPS transport is not limited to the initial re-entry into water; it persists until either the propagule becomes dislodged or dies, potentially placing multiple water bodies at risk.

In a study of the risk for transport of non-native insect species to the U.S. via foreign cargo trade, (Work et al. 2005) found that risk was highest for refrigerated maritime containers followed by non-refrigerated maritime containers, air cargo, and finally overland transport.

Approximately 2% of cargo arriving at U.S. maritime ports, border crossings, and airports has been inspected since 1972 and the number of plant pests intercepted is a linear function of the number of inspections conducted (Work et al. 2005). The volume of imported goods and inadequate funding and staffing contribute to these overall low inspection rates.

## 3. Freshwater IAPS of concern

IAPS of concern to the Micronesia Region include those species that:

- are already present within the region
- are likely to occur in high risk invasion pathways
- have biotic characteristics that could potentially lead to successful invasions such as ecological versatility, competitive ability, reproductive output and dispersal mechanisms, ability to colonize undisturbed habitats and similarity of climate from source to new habitat
- have known negative environmental impacts
- and have known negative impacts on economic and social uses of water and the environment

### 3.1 The Aquatic Weed Risk Assessment Model (AWRAM) (Champion and Clayton 2000, 2001) was used to assign risks of individual IAPS to the Region see Appendix B for details.

### 3.2 Field Survey Results

Field visits were conducted in January and April 2010 to survey freshwater aquatic plants established in the region (Table 4) and plants available for sale in commercial settings, such as open-air markets and aquarium stores (Table 5). Sites were visited on Guam (Figure 3-1), Saipan, CNMI (Figure 3-2), Yap, FSM (Figure 3-3), Pohnpei, FSM (Figure 3-4), and Palau (Figure 3-5). Survey sites were selected based on previous USFS vegetation surveys (Cole et al. 1987; Falanruw et al. 1987; MacLean et al. 1986) and local knowledge provided by natural resource staff and guides on the islands. Detailed survey methods and results are available in Appendix B.

Significant findings included the first record of *Monochoria vaginalis* within Micronesia in a small stream on the southern coast of Guam. *M. vaginalis* is an ornamental emergent to floating species from Indonesia (Horn 2002), Malaysia, Japan (including Okinawa), and Taiwan (Wagner et al. 1999). It has naturalized in rice fields of California (Horn 2002) and invasive populations are known in Fiji and several of the Hawai'i islands (Smith 1979, Wagner and Herbst 1995, Wagner et al. 1999). This species is considered edible, medicinal and has an attractive flower, suggesting that it was a likely intentional introduction (Yang et al. 2008). *M. vaginalis* and its congenor, *M. hasata,* are listed noxious weeds by the U.S. Federal Government (7 CFR § 360.200).

Previously abundant populations of hydrilla (*Hydrilla verticillata*) and curly-leaf pondweed (*Potamogeton crispus*) in Fena Valley Reservoir, Guam were not found, apparently due to grazing by two introduced Tilapia species (*Oreochromis massambicus* and *Tilapia zillii*). *H. verticillata* was present, however, in tributaries to, and downstream of, the reservoir and was found in numerous other streams throughout southern Guam.

*Eichhornia crassipes* was widespread in the region. *E. crassipes* is native to the Amazon River basin in South America, but has been widely distributed as an ornamental floating leafed plant. It was found naturalized in Agana Swamp, Guam, where it was also observed in an individual's bucket; it was apparently collected there for transport. On Pohnpei, *E. crassipes* and *Pistia stratiotes* were naturalized in numerous ditches. On Yap, *E. crassipes* and *Ipomoea aquatica* were found in similar habitat. It was reported that *E. crassipes* flowers were brought to church each week on both these islands.

*H. verticillata*, *E. crassipes*, *P. stratiotes* and *I. aquatica* were available for sale in open-air markets in at least one location visited within Micronesia. These species, as well as *Salvinia* spp., *Nymphaea* spp., *Nelumbo* spp. were also offered for sale at numerous nurseries with ornamental pond plants. *I. aquatica*, a floating-leaved plant native to China, was widely cultivated and sold as an edible plant on all islands visited, as it is throughout many regions of the Pacific, Africa, South America, and Australia (Fang and Staples 1995).

In addition to these findings during field sampling, two websites of local flora and habitats indicated a population of *Salvinia natans* may be naturalized within the Malojloj watershed (Pauliluc River), Guam. This species was observed for sale at a nursery within this watershed.

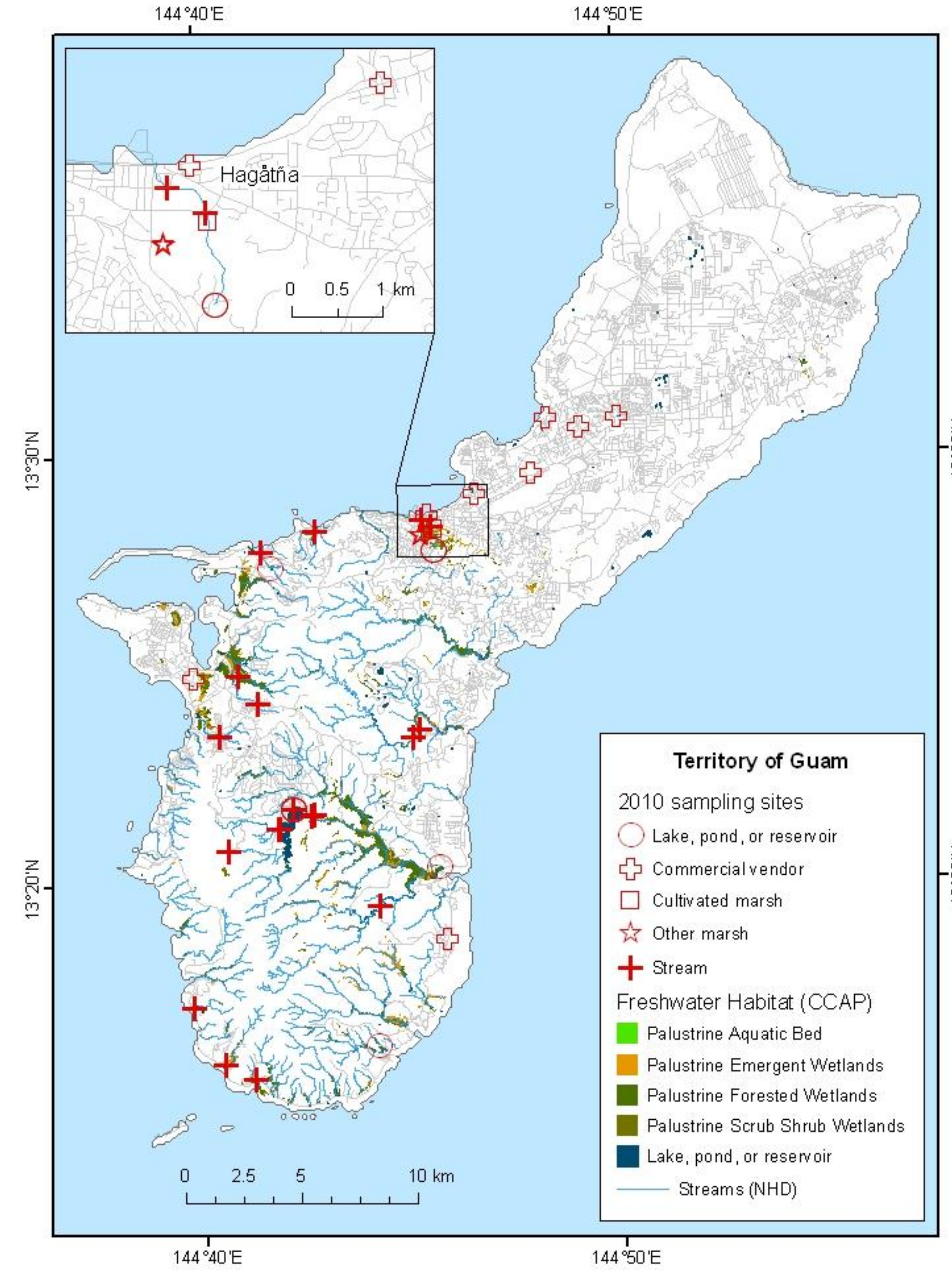


**Figure 3-1: Freshwater habitats and aquatic plant survey sites in the Territory of Guam. Freshwater habitat data are from the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (NOAA-CSC 1995-present)and stream data are from the U.S. Geological Survey (USGS) National Hydrographic Dataset (NHD).**

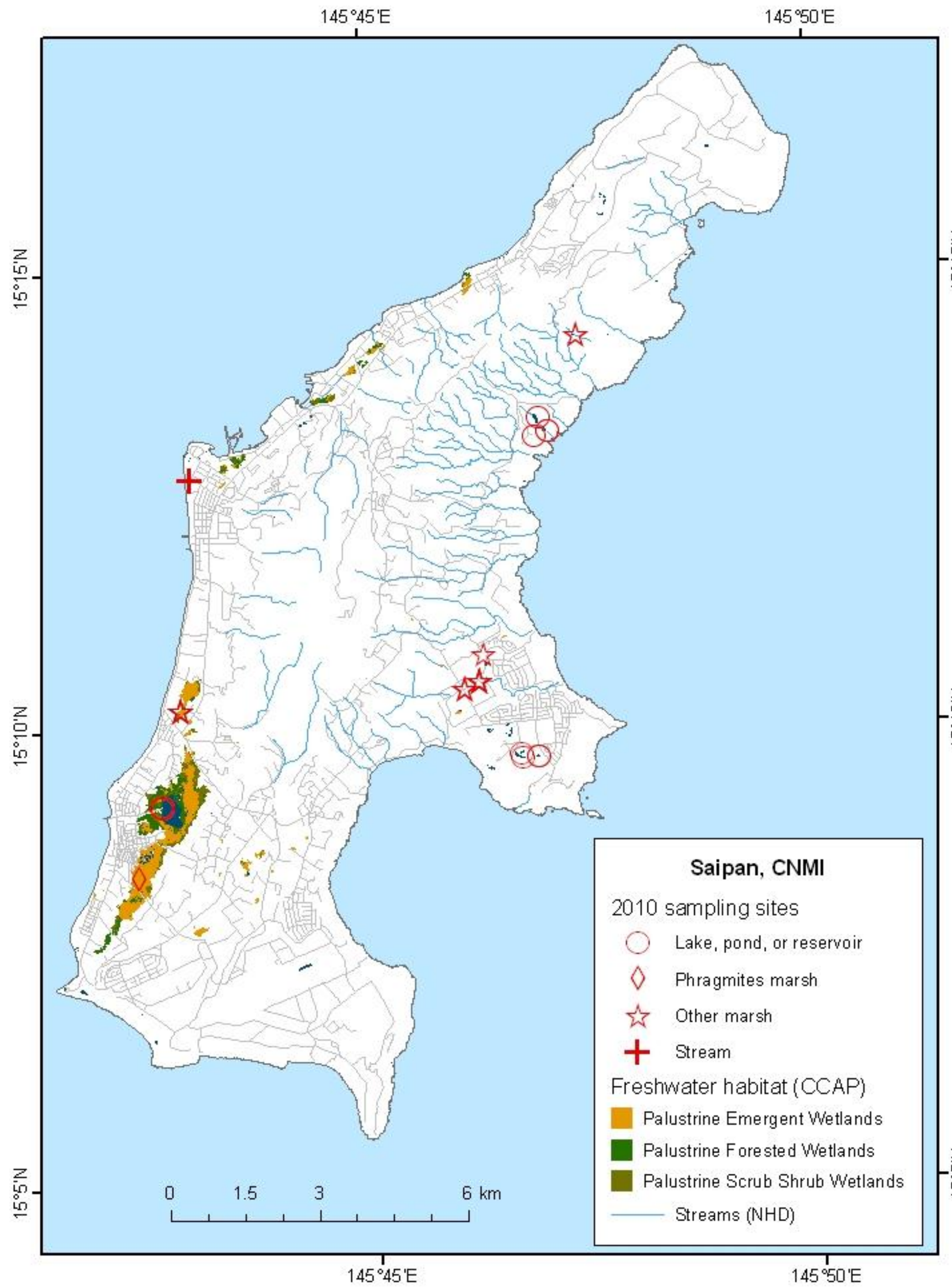


**Figure 3-2: Freshwater habitats (NOAA-CSC 1995-present) and aquatic plant survey sites in Saipan, CNMI.**

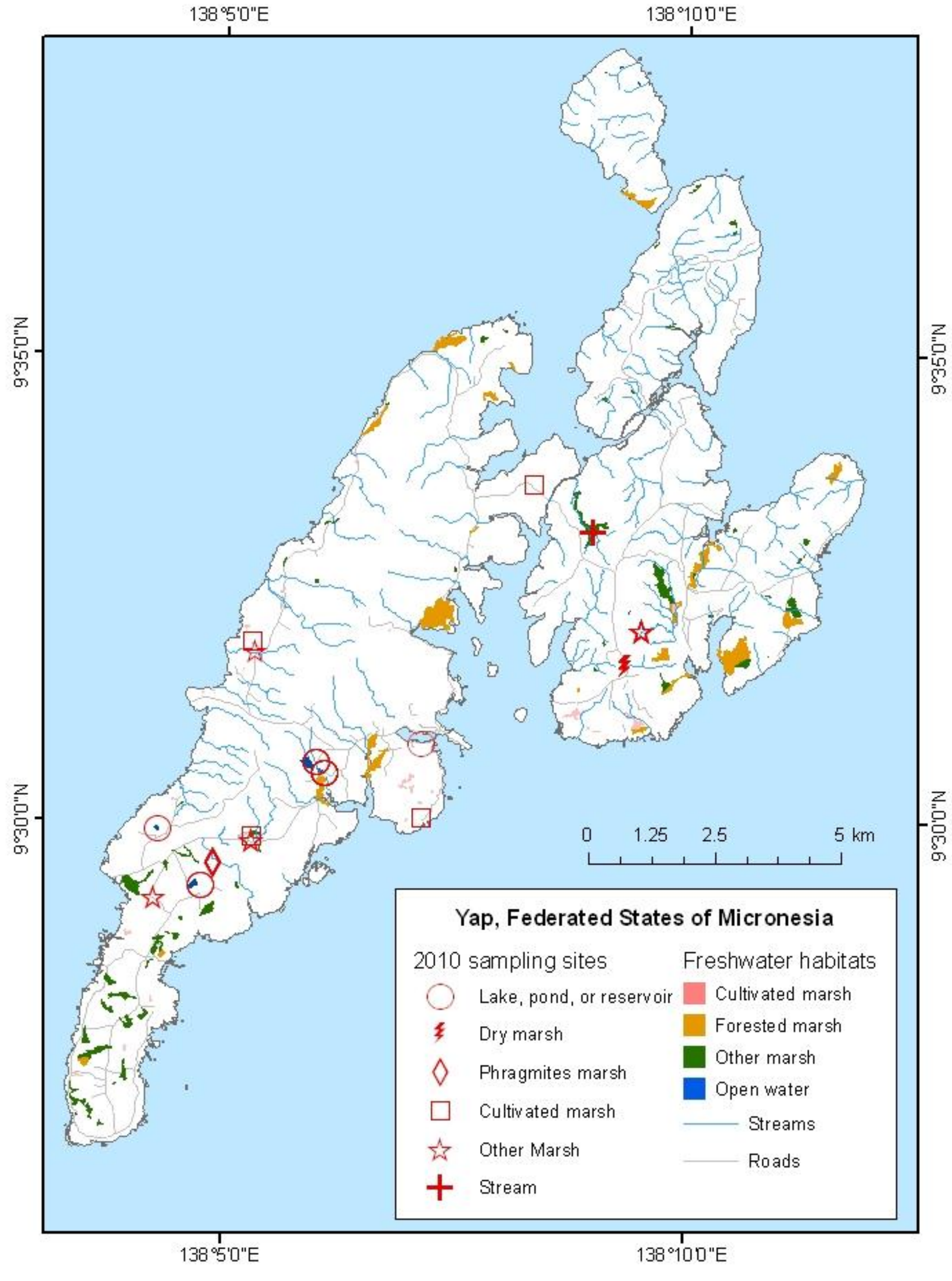


**Figure 3-3: Freshwater habitats (Falanruw et al. 1987) and aquatic plant survey sites in Yap, FSM.**

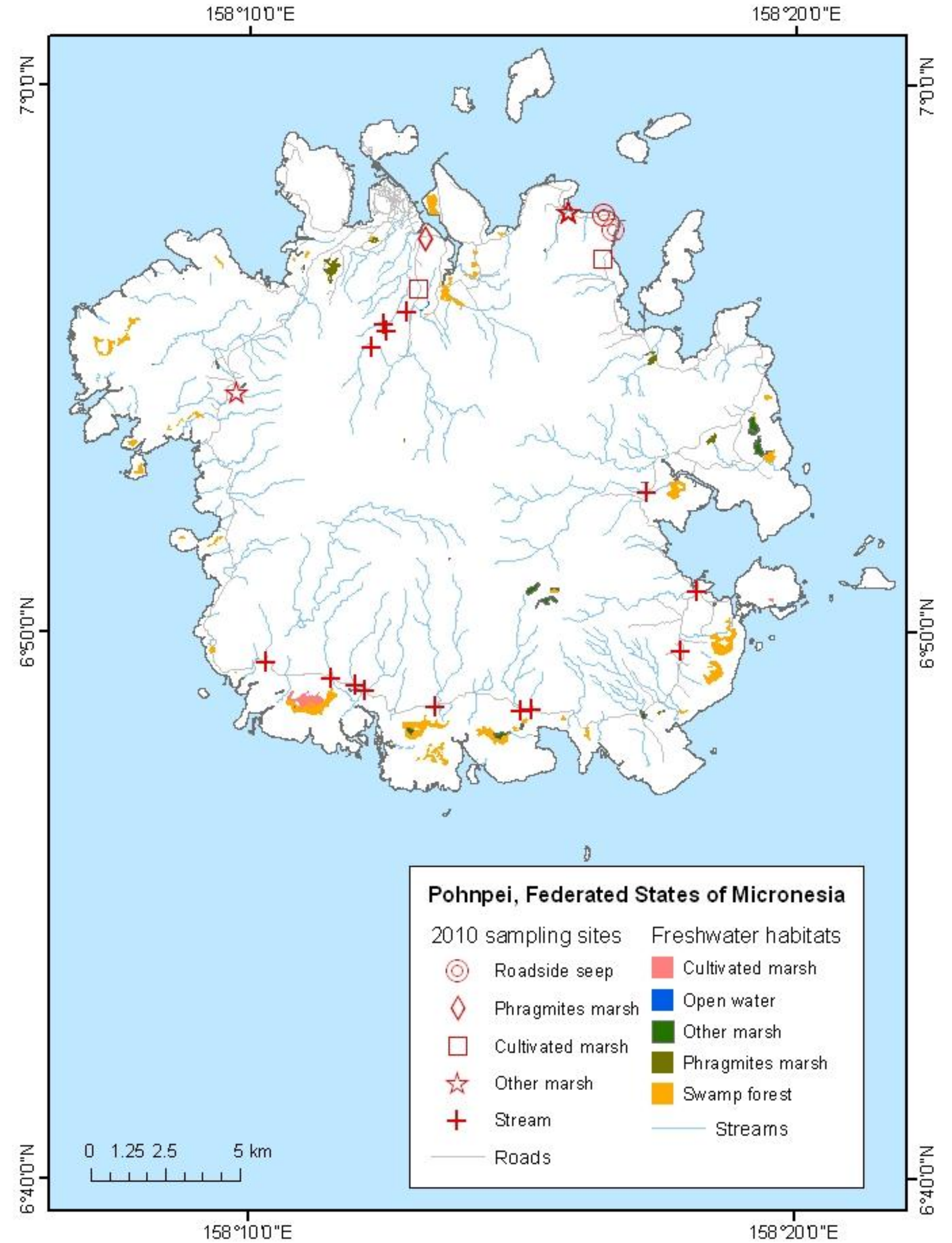


**Figure 3-4: Freshwater habitats (MacLean et al. 1986) and aquatic plant survey sites in Pohnpei, FSM.**

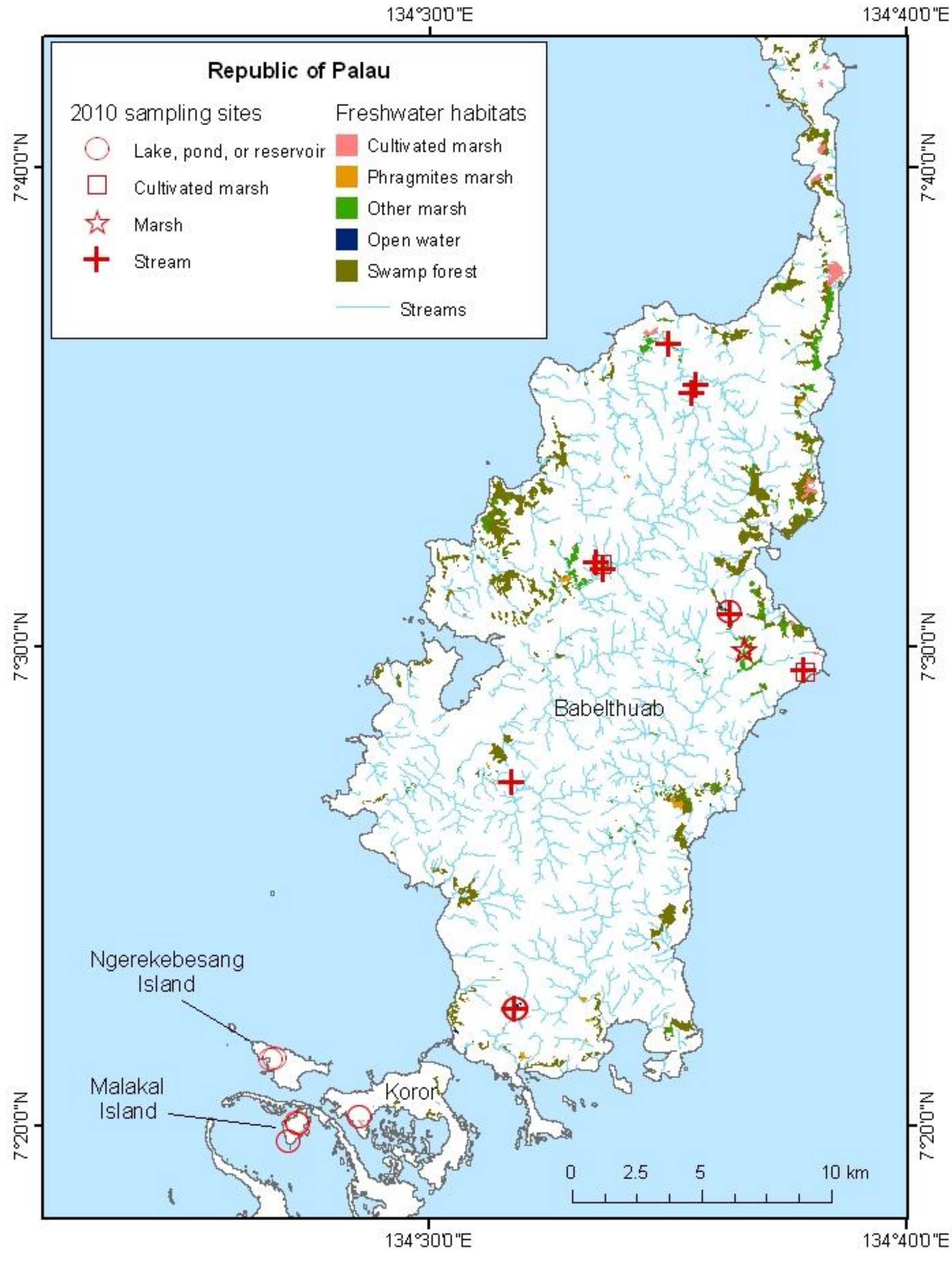


**Figure 3-5: Freshwater habitats (Cole et al. 1987) and aquatic plant survey sites in the Republic of Palau.**

**Table 3-1: Naturalized plant populations found during field sampling, January and April 2010; ‘x’ – native, ‘I’ – introduced.**

| Scientific name | Common name | Guam | Saipan | Pohnpei | Yap | Palau |
|---|---|---|---|---|---|---|
| *Acacia auriculariformis* | earleaf acacia | | | | I | |
| *Acrostichum aureum* | golden leatherfern | | | | x | |
| *Actinoscirpus grossus* | giant bulrush | | x | | | x |
| *Ageratum conyzoides* | tropical whiteweed | | | | | I |
| *Alternanthera sessilis* | sessile joyweed | | | x | | x |
| *Bacopa monnieri* | water hyssop | x | x | | | |
| *Blyxa aubertii* | roundfruit blyxa | | | x | | x |
| *Cassytha filiformis* | devil’s gut | | | | x | |
| *Casuarina equisetifolia* | beach sheoak | | | | x | |
| *Cayratia trifolia* | threeleaf cayratia | | | | x | |
| *Centella asiatica* | spadeleaf | | | x | | |
| *Ceratophyllum demersum* | coon’s tail | x | | | | |
| *Ceratopteris thalictroides* | watersprite | x | | | x | x |
| *Chara sp.* | muskgrass, stonewort | x | | | | |
| *Colocasia esculenta* | soft taro | | | | I | I |
| *Commelina diffusa* | climbing dayflower | | | I | | |
| *Cyclosorus interruptus* | cyclosorus fern, swamp fern | | | x | x | x |
| *Cyperus compressus* | poorland flatsedge | | | | I | |
| *Cyperus difformis* | variable flatsedge | I | | I | | |
| *Cyperus javanicus* | Javanese flatsedge | | | | x | |
| *Cyperus polystachyos* | manyspike flatsedge | x | | x | | |
| *Cyperus prolifer* | miniature flatsedge | x | | | | |
| *Cyperus sp.* | flatsedge | | | | x | |
| *Cyrtosperma chamissonis* | giant swamp taro | | | | I | I |
| *Dicronopteris linearis* | Old World forked fern | | | | x | |
| *Echinochloa crus-gallii* | barnyardgrass | | | I | | |
| *Echinodorus osiris* | melon sword | I | | | | |
| *Echinodorus cordifolius* | spade leaf sword | I | | | | |
| *Eclipta prostrata* | false daisy | | | I | | I |
| *Eichhornia crassipes* | water hyacinth | I | I | I | I | |
| *Eleocharis dulcis* | Chinese water chestnut | | | | I | |
| *Eleocharis geniculata* | Canada spikesedge | x | | | x | x |
| *Eleocharis ochrostachys* | spikerush | | | | x | x |
| *Eriocaulon sexangulare* | | | | | x | x |
| *Fimbristylis dichotoma* | forked fimbry | | | x | x | x |
| *Fimbristylis littoralis* | fimbry, grass-like fimbristylis | x | | x | x | |
| *Fimbristylis sp.* | fimbry | | | | x | |
| *Fuirena umbellata* | yefen | | | | x | x |

**Table 3-1 (continued): Naturalized plant populations found during field sampling, January and April 2010. ; ‘x’ – native, ‘I’ – introduced.**

| Scientific name | Common name | Guam | Saipan | Pohnpei | Yap | Palau |
|---|---|---|---|---|---|---|
| *Hanguana malayana* | | | | | x | x |
| *Hibiscus tiliaceus* | sea hibiscus | x | | | x | x |
| *Hydrilla verticillata* | Hydrilla | I | | | | |
| *Hyptis capitata* | false ironwort | | | I | I | I |
| *Ipomoea aquatica* | swamp morning-glory, Chinese water spinach | I | I | I | I | I |
| *Isachne confusa* | isachne | | | | x | x |
| *Ischaemum polystachyum* | | | | x | x | x |
| *Kyllinga brevifolia* | shortleaf spikesedge | | | x | | |
| *Kyllinga sp.* | spikesedge | | | | | x |
| *Lemna aequinoctialis* | lesser duckweed | x | | | | |
| *Lepironia articulata* | grey sedge | | | | x | |
| *Limnophila aromatica* | rice paddy herb | | | | x | x |
| *Lindernia antipoda* | sparrow false pimpernel | | | x | | x |
| *Ludwigia hyssopifolia* | seedbox | | | x | x | x |
| *Ludwigia octovalvis* | Mexican primrose-willow | x | | x | x | x |
| *Lycopodium cernuum* | staghorn clubmoss | | | | x | |
| *Lygodium microphyllum* | small-leaf climbing fern | | | | x | |
| *Mecardonia procumbens* | baby jump-up | | | x | x | |
| *Melaleuca quinquenervia* | punktree | | | | I | |
| *Monochoria vaginalis* | heartshape false pickerelweed | I | | | | |
| *Nepenthes mirabilis* | common swamp pitcherplant | | | | x | x |
| *Nephrolepis sp.* | sword fern | | | | x | |
| *Nitella sp.* | brittlewort | | | | x | x |
| *Nymphaea caerulea var. zanzibarensis* | Cape waterlily | I | | | | I |
| *Pandanus sp.* | pandanus palm | | | | x | |
| *Persicaria minus var. procera* | pygmy smartweed | | | | | x |
| *Phragmites vallatoria* | Khagra reed, *P. karka* | x | x | x | x | x |
| *Phyla nodiflora* | turkey tangle, fogfruit | | | | I | |
| *Pistia stratiotes* | water lettuce | I | | I | | |
| *Polygala paniculata* | milkwort, root beer plant | | | | x | |
| *Potamogeton nodosus* | longleaf pondweed | x | | | | |
| *Rhynchospora corymbosa* | matamat | | | x | x | x |
| *Sphagneticola trilobata* | Bay Biscayne creeping-oxeye | I | I | | I | I |
| *Tradescantia sp.* | spiderwort | | | I | | |
| *Urochloa mutica* | para grass | | | | | x |
| *Utricularia gibba* | humped bladderwort | | | | | x |
| *Utricularia uliginosa* | Asian bladderwort | | | | | x |

**Table 3-2: Live plants found for commercial sale during field sampling in January and April 2010 in open-air markets, plant nurseries and pet/aquarium stores on Guam.**

| Scientific name | Common name |
|---|---|
| *Anubias sp.* | dwarf anubias |
| *Ceratophyllum demersum* | common hornwort, coontail |
| *Cryptocoryne spp.* | water trumpet |
| *Echinodorus spp.* | burhead |
| *Eichhornia crassipes* | water hyacinth |
| *Hydrilla verticillata* | hydrilla |
| *Lemna minuta* | least duckweed |
| *Myriophyllum aquaticum* | parrot feather |
| *Nelumbo nucifera* | sacred lotus |
| *Nymphaea caerulea var. zanzibarensis* | Cape waterlily |
| *Nymphaea elegans* | tropical royalblue waterlily |
| *Nymphaea spp.* | waterlily |
| *Pistia stratiotes* | water lettuce |
| *Sagittaria latifolia* | broadleaf arrowhead |
| *Sagittaria sp.* | arrowhead |
| *Salvinia cucullata* | Asian watermoss |
| *Salvinia natans* | eared watermoss, floating watermoss |
| *Salvinia spp.* | watermoss |
| *Spirodela polyrrhiza* | greater duckweed, common duckweed |

## 4. Susceptible Freshwater Habitats

An essential requirement for the establishment of invasive plants in any region is the availability of suitable habitat. For freshwater IAPS, suitable habitats include permanent and intermittent freshwater wetlands, lakes and other standing waters, and rivers and streams. In Micronesia these habitats are primarily limited to high volcanic, raised atoll, and raised continental shelf islands, which include Guam; most islands in CNMI; Kosrae, Pohnpei, Yap, and some of the islands of Chuuk State in FSM; and several islands in the Republic of Palau (Stemmermann and Proby 1978b). Freshwater habitats on low atoll islands in the region are restricted to cultivated wetlands, although there is one small freshwater pond in the center of Lib Island, Republic of the Marshall Islands (Dahl 1980). Land-cover data from a variety of sources were analyzed to characterize the freshwater habitats in the region (Table 4-1). Vegetation surveys conducted for the U.S. Army Corp of Engineers (USACE)[1] and the USFS[2] describe wetlands and their distributions throughout the Micronesian region. Wetland habitats were classified into categories including lowland swamp forests, upland wetlands, cultivated and other ruderal wetlands, riparian wetlands, lakes, reservoirs, and ponds[3]. Pictures of representative habitats are presented in **Error! Reference source not found.**. Mangrove swamps and other habitats with salinities greater than 5‰ (parts per thousand) were not included in this assessment. Although the percentage of land area covered by freshwater is low throughout region (Table 4-2 and **Error! Reference source not found.**), freshwater areas are important for fish, wildlife, food production, recreation, and drinking water.

Forested marsh accounted for the greatest area of freshwater habitat in the region as estimated using C-CAP and USFS land cover data (Table 4-2). Palau and Guam have the most forested marsh area followed by Kosrae and Pohnpei. Non-forested marsh is the next most extensive freshwater habitat followed by lakes, ponds, and reservoirs. Although stream length data is not necessarily comparable across the different data sources with great confidence, Palau, Guam, and Pohnpei have more stream kilometers than other islands.

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[1] Moore et al. 1977; Stemmermann and Proby 1978a; Stemmermann and Proby 1978b
[2] Cole et al. 1987; Falanruw et al. 1987a; MacLean et al. 1986; Whitesell et al. 1986
[3] These classifications are similar but more detailed than classification schemes used by the NOAA Coastal Change and Analysis Program (C-CAP) and the USFWS National Wetlands Inventory (NWI) to characterize more recent conditions.

**Table 4-1: Primary data sources used to summarize freshwater resources[1].**

| Region | Data source | Image date(s) |
|---|---|---|
| Territory of Guam | NOAA C-CAP (NOAA-CSC 1995-) | 2005 |
| Commonwealth of the Northern Mariana Islands | NOAA C-CAP (NOAA-CSC 1995-) | 2003-2005 |
| Federated States of Micronesia | | |
| *Kosrae State* | USFS (Whitesell et al. 1986) | 1976 |
| *Pohnpei State* | USFS (MacLean et al. 1986) | 1976 |
| *Yap State* | USFS (Falanruw et al. 1987a) | 1976 |
| *Chuuk State* | | |
| *Tol, Paata, Polle, Fanapanges, Romanum, Udot, Eot, Pwipwi, and Totiw Islands* | USFS (Donnegan et al. 2010) | 2006 |
| Republic of Palau | USFS (Cole et al. 1987) | 1976 |
| Republic of the Marshall Islands | Dahl 1980 | No data |

[1]Data sources used to characterize freshwater habitats in the region included NOAA C-CAP land cover data for Guam and CNMI derived from 2000s era satellite imagery and ground verification and USFS vegetation surveys based on 1970s era aerial photographs and 1980s era ground verification. USFS Forest Inventory and Analysis Program (FIA) vegetation survey data, which is based on satellite imagery and ground verification, was used for several of the Chuuk Islands since C-CAP and USFS vegetation survey data were not available (Table 2). Although the FIA vegetation survey data is available for much of the region, and is more recent, it was only used when other data sources were unavailable because the FIA wetlands classification scheme is relatively coarse compared to the earlier USFS vegetation surveys and recent C-CAP land cover data. For example, the FIA survey data does not differentiate between fresh and brackish water.

**Table 4-2: Land area of selected islands within the Micronesia, percent of land covered by freshwater habitats, and stream density.[1]**

| Island | Land area (ha) | Percent of land covered by freshwater habitats[1] | Stream density (m/ha)[2] |
|---|---|---|---|
| Guam | 54376 | 3 | 8 |
| Saipan, CNMI | 11893 | 2 | 9 |
| Rota, CNMI | 8511 | 0 | 0 |
| Tinian, CNMI | 10122 | < 1 | 0 |
| Kosrae, FSM | 11397 | 5 | 5 |
| Pohnpei, FSM | 36585 | 2 | 9 |
| Chuuk, FSM (high islands) | 8758 | 3 | 5 |
| Republic of Palau | 41229 | 5 | 15 |
| RMI | 18100 | 0 | 0 |

[1] NOAA C-CAP and USFS land cover. [2] USGS National Hydrographic Dataset and USGS topographic maps.

**Figure 4-1: Representative freshwater habitats in the Micronesia Region (clockwise from upper right): large stream on Pohnpei; upland savannah wetland with *Phragmites vallatoria* on Yap; ruderal roadside seep with *Eichhornia crassipes* on Pohnpei; cultivated taro wetland on Guam; Fena reservoir on Guam; and a small bomb crater reservoir with *Utricularia gibba* on Palau.**

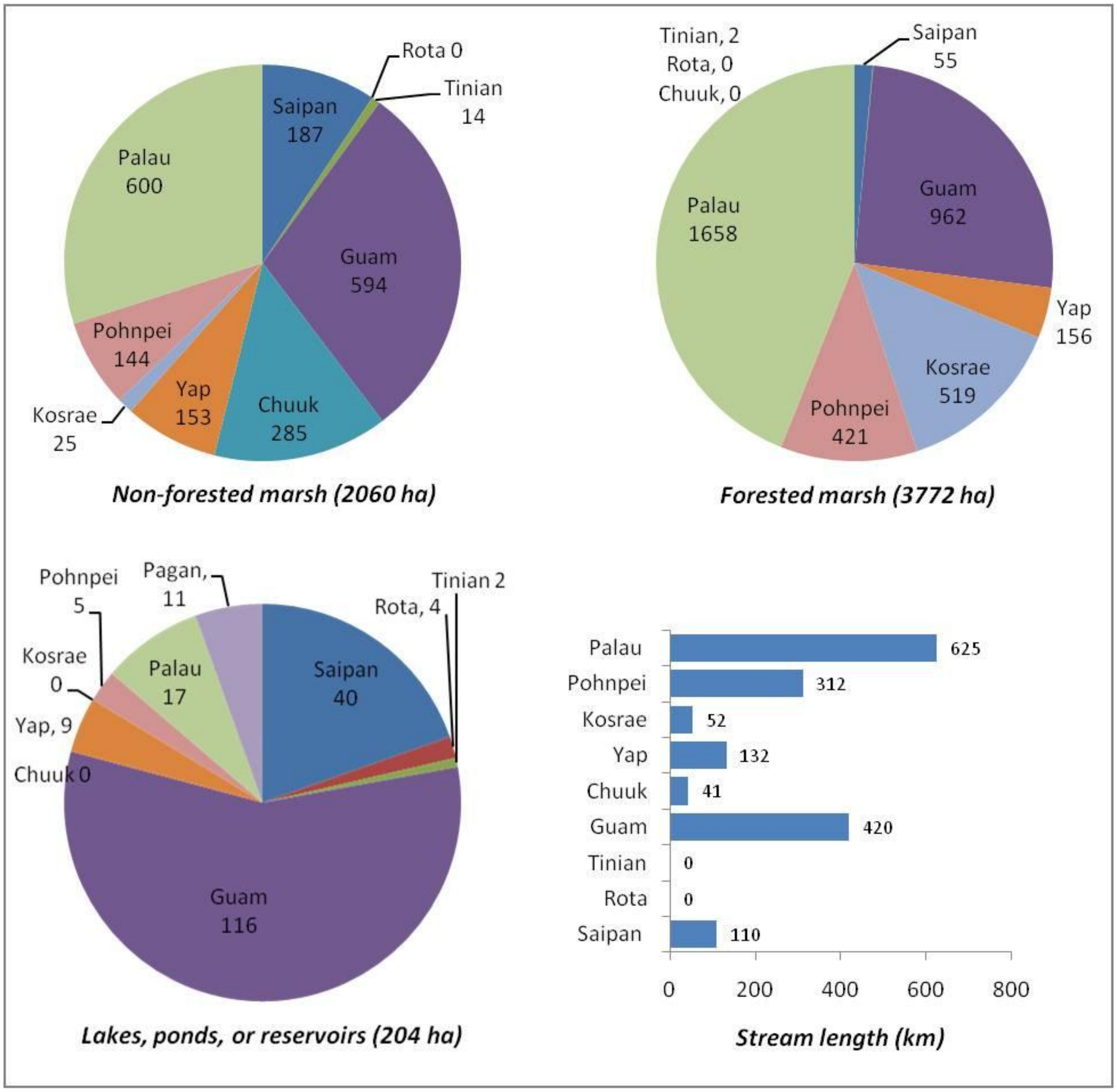


**Figure 4-2: Summary of freshwater habitats in the Micronesia Region.**

## 4.1 Freshwater wetlands

### 4.1.1 Lowland swamp forests

Swamp forests are by far the most extensive type of freshwater wetlands in the region and cover large areas of Palau, Kosrae, Pohnpei and Guam. Swamp forests are often to the landward side of mangrove swamps where brackish water is diluted by fresh water. Canopy cover in swamp forests ranges from high to low. Swamp forests with low canopy cover and sufficient light penetration are ideal for growing taro; consequently forest cover has been thinned or cleared in many areas for agriculture. Typical tree species present in high-canopy swamps vary across the region but include *Campnosperma brevipetiolata*, *Terminalia carolinensis* (Ka tree), *Horsfieldia nunu*, and *Calophyllum cholobtaches*. Forests with low canopy cover include *Hibiscus tiliaceus*, *Barringtonia racemosa* (powder-puff tree), and *Scirpodendron ghaeri* (Stemmermann and Proby 1978a).

### 4.1.2 Open canopy swamps and wetlands

Several types of non-forested wetlands are common throughout the region including wetlands dominated by the tall reed *Phragmites vallatoria* (Khagra reed), wetlands with low sedge, grass, and herb species; and savannah wetlands with scattered trees such as *Pandanus spp.*(Stemmermann and Proby 1978a). Many of these wetlands are seasonally dry.

### 4.1.3 Cultivated and other ruderal wetlands

Wetland cultivation of the taro species *Cryptosperma camissonis* (giant or swamp taro) and *Colocasia esculenta* (soft taro) is an important component of Micronesian food production and culture (Manner 2008). In Kosrae, FSM, for example, about 97% of households cultivate taro in wetlands (Drew et al. 2005). Creation of swamp taro patches often involves clearing or thinning swamp forests, destruction of open canopy marsh, conversion of brackish mangrove swamps to freshwater, or creation of new marsh by excavating pits. Excavated taro pits are the only types of freshwater wetlands present on the numerous atolls throughout Micronesia (Stemmermann and Proby 1978b).

Swamp taro cultivation in Micronesia is declining due to increased reliance on dry-land crops such as sweet potatoes and cassava, imported foods such as rice, and the time and labor constraints associated with a more urbanized lifestyle (Manner 2008). Furthermore, human emigration from the outer islands has led to an increase in abandoned or neglected taro pits. These pits have been found to be susceptible to invasive aquatic species, such as water hyacinth. Other disturbed-area wetlands include roadside ditches, seeps, and construction areas. Although these ruderal areas are not as extensive as other wetland types (Stemmermann and Proby 1978b), their accessibility puts them at high risk for invasion.

## 4.2 Rivers and streams

The extent of streams and rivers in Micronesia varies considerably from island to island based on watershed size, soil permeability, rainfall amounts, and season. Because many of the islands are small and composed of permeable limestone, surface flows are typically limited to high rainfall events. Permanent rivers and streams occur on the large islands of Saipan, Kosrae, Pohnpei, Chuuk, Palau and the southern half of Guam that are composed of less permeable geological materials and where precipitation is high.

Precipitation patterns vary across the region. On a large scale, there is an east-west zone of high annual precipitation from 4-8°N across Micronesia. Precipitation drops off steadily north of this zone and the dry season becomes more prolonged. The islands of Kosrae and Pohnpei experience over 150 inches of rain annually with no appreciable dry season (Figure 4-3). Further north, annual rainfall drops to 80 inches and there is an extended dry season at Saipan, CNMI. Rainfall decreases to around 40 inches per year north and east of Saipan (Lander and Guard 2003). The result of the observed rainfall patterns is larger and more permanent streams in Kosrae, Pohnpei, and Palau than on islands to the north.

Most streams and rivers in the region are heavily shaded, which limits the potential for growth of freshwater aquatic plants. Riparian areas in urban and suburban areas are often denuded of vegetation and have more light available for the growth of aquatic plants. Riparian vegetation in upland forested areas of the wetter islands and riparian vegetation along rivers running through swamp forests is also similar to surrounding vegetation (Stemmermann and Proby 1978b). Grass species such as *Ischaemum polystachyum* are often found along riverbanks. Where light is sufficient for aquatic plants to survive, other factors may limit establishment and growth. For instance, high stream flow can scour streambeds and remove freshwater aquatic plants such as *Hydrilla verticillata* (Brent Tibbatts, Guam DFW, pers. comm.) and the sediments necessary for rooting.

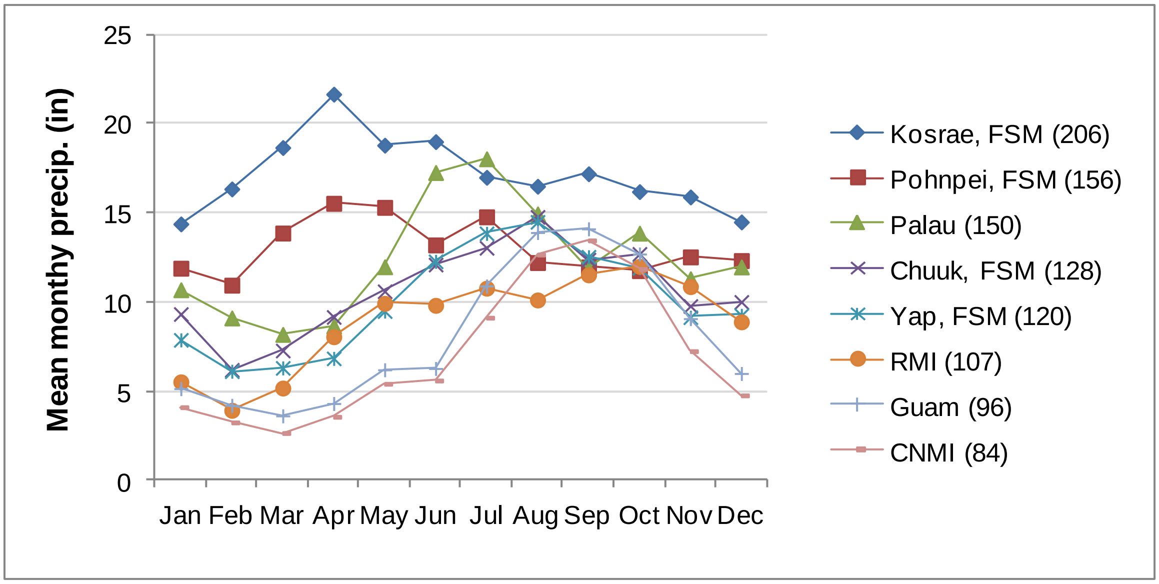


**Figure 4-3. Mean monthly precipitation and annual precipitation (in parentheses) measured throughout the Micronesia region. Data are from U.S. and cooperating Government of Guam agencies (Lander and Guard 2003).**

## 4.3 Lakes, reservoirs, and ponds

Lakes and reservoirs are not common in the region. Some notable examples include Fena Reservoir, Guam; Lake Susupe, CNMI; and Ngardok Lake, Palau. Fena Reservoir is the largest freshwater body and constitutes nearly half of the total surface area of lakes, ponds and reservoirs in the region. The non-native freshwater plant species hydrilla (*Hydrilla verticillata*) and curly leaf pondweed (*Potamogeton crispus*) were historically abundant in Fena Reservoir but are now sparse due to grazing pressure by introduced tilapia (Brock and Takata 1956; Nelson and Eldredge 1991). Lake Susupe is the second largest water body in the region, however, the lake is brackish (Wong and Hill 2000) and therefore not suitable for many species of freshwater aquatic plants. The largest natural freshwater lake in Micronesia is Lake Ngardok on the island of Babeldaob, Palau (Yeung and Wong 1999). The most numerous standing water bodies in the region include bomb crater ponds, golf course ponds, and municipal water supply reservoirs. Freshwater aquatic plant species common to many of these water bodies include *Utrichularia* spp. and *Chara* spp.

# 5. Aquatic Plant Treatment and Control Methods

There are numerous mechanical, physical, biological, and chemical methods available for managing emergent, floating and submersed aquatic plants. An integrated approach to aquatic plant management requires consideration of the abundance and distribution of the plants present, management goals, site-specific characteristics, legal and economic constraints, and possible impacts of management activities. Although there are limited examples of AIPS eradication and control efforts in the literature or the popular media, Simberloff (2009) argues that this is not a reflection of reality for two reasons: resource managers are more focused on management rather than publication of success stories, and unsuccessful efforts receive more interest in the media.

## 5.1 Mechanical Control

Mechanical techniques have been utilized for many years to control nuisance aquatic vegetation. A variety of mechanical methods exist, including hand tools; cutting, harvesting, chopping, and rotovation machines; and diver-operated suction harvesting. Mechanical methods often provide immediate results, cause little shoreline damage, are amenable to use in isolated areas, and can be used for large or small scale projects. Drawbacks to mechanical control include potentially high costs, the necessity of repeated treatments during the year, and the disposal of the collected plant material. More importantly, these methods may also promote fragmentation and, as a result, subsequent proliferation of certain species of macrophytes.

### 5.1.1 Hand removal

Hand removal, using cutters, rakes, or bare hands to remove plants, is the most common method of weed removal. This labor-intensive technique works best on small infestations or for small areas such as around docks. With hand cutting, plant shoots are cut below the water's surface, but roots are not removed. A simple design for a cutter uses two single-sided blades forming a "V" shape, connected to a handle with a rope. The cutter can be thrown from the shore, dock, or other floating structure. As the cutter is pulled through the water, it cuts a swath of vegetation. Raking involves tearing the plants from the sediment with a regular garden or thatch rake; the rake-head may be attached to a rope, allowing removal from deeper waters. Any type of hand removal is likely to create plant fragments, which should be removed from the water and disposed of away from the shoreline to prevent recolonization. Hand removal methods are likely to disturb sediments and increase turbidity and require repeated application during the year to maintain adequate control.

### 5.1.2 Harvesting

Mechanical harvesters are large specialized machines that cut and collect aquatic plants. The cut plants are removed from the water by a conveyor system and stored on the harvester or a barge following the harvester, until they can be disposed of on shore. Harvesting can target specific areas in a lake, creating boat channels for example, while leaving other areas untreated. In removing the plants from the water column, the nutrients stored within the plants are also removed. Since harvesting only removes the upper portion of the plant, some plant material remains as habitat for fish and other organisms(Gettys et al. 2009). The large size of most harvesters limits access to shallow areas or around structures such as docks. Bottom obstructions such as logs or stumps may make harvesting difficult and shallow lakes with loose organic sediment are not suitable for harvesting.

### 5.1.3 Cutting

Cutter or shredder boats are specially designed to cut aquatic vegetation below the water surface. Unlike harvesting units, however, cutting equipment does not remove plant fragments from the water. Fragments generated from cutting or shredding are allowed to flow downstream on river currents or with tidal action and may spread an infestation of IAPS. Cutting is used in situations where removal of fragments is not feasible for logistical or economic reasons.

### 5.1.4 Rotovation

A rotovator is an aquatic rototiller, with blades that till the sediment and dislodge plants and roots. Floating booms may be placed around the treatment area to collect plant fragments created in this process; these fragments may then be removed from the water mechanically or by hand collection. This method is not species specific and since it disturbs the sediment, it may increase turbidity and negatively impact benthic organisms and fish-spawning areas.

## 5.2 Physical Control

Physical control methods to control existing plants involve modifying the environment to limit or eliminate conditions favorable to plant growth. Physical methods include benthic barriers, drawdown, aeration, nutrient inactivation, sediment agitation, steepening of banks, water column dyes, and others. Many physical control measures are technically simple to implement, leave little to no chemical residue, and can be very site specific. These benefits are weighed against the fact that the treatment time required to achieve the desired result can be long, often require intensive personnel resources, and are rarely species specific.

### 5.2.1 Benthic barriers

Benthic barriers are gas-permeable sheeting materials installed directly on the lake sediments and held in place by sandbags, pins, rocks, bricks, or other objects. Growth of rooted aquatic plants is prevented by light limitation and physical contact with the sediment. A variety of materials may be used as benthic barriers including burlap, PVC, or woven synthetics such as geotextile fabrics. The material should be gas permeable to allow for the escape of gas produced during plant decomposition beneath the barrier and sediment respiration; alternatively, the material by be strategically cut to allow venting of gases. Plants typically die within a few months, but barriers may be installed for longer periods around high-use areas such as boat launches in order to prevent recolonization. Barriers require periodic cleaning to remove sediment deposition to prevent plants from rooting on top of the barrier.

### 5.2.2 Drawdown

Where water control structures are in place, strategic lowering of water levels can control certain emergent or rooted aquatic plants. Siphoning or pumping can be used if gravity draining is not an option.

Effectiveness is maximized when the depth of the drawdown exceeds the maximum depth of colonization of the target species and the sediments are dried for a sufficient time to kill aquatic plants (Nichols 1991); time required for drying varies with the local climate and substrate, but generally ranges between 4-8 weeks. Drawdown may not be effective for free-floating aquatic species, e.g., *Pistia stratiotes* or *Salvinia* spp., that retreat with diminishing water levels unless the entire water body can be dewatered. Species with desiccation-resistant propagules (seeds or resistant vegetative structures) like *Hydrilla verticillata* are adapted to seasonal drying and can persist or even increase following periods of drawdown (Gettys et al. 2009).

### 5.2.3 Aeration/mixing

Aeration/mixing devices that destabilize the water column and can alter nutrient concentrations in lakes and ponds. Physical disruption of water column stability can alter the phytoplankton community by increasing mixing depth and consequently the light regime that phytoplankton experience. Destabilization of the water column and increased mixing can also reduce the competitive advantage of cyanobacteria that can regulate their buoyancy. Induction of surface currents by aeration/mixing devises can reduce the cover of free-floating plants, like duckweeds; however, this method will not eliminate or effectively control rooted aquatic plants.

### 5.2.4 Nutrient inactivation

Applications of alum (aluminum sulfate), iron salts, or calcium (lime) reduces water column concentrations of phosphorus, which commonly limits phytoplankton abundance in lakes and ponds, resulting in reduction in phytoplankton abundance in the water column (Bellaud 2009). Nutrient inactivation may reduce growth rates of floating aquatic plant species that obtain all their nutrients from the water column, but rooted plants have access to sediment phosphorus, so the method is not effective on rooted plants (Nichols 1991). Increased light penetration due to reduction in phytoplankton abundance in the water column may actually increase growth of macrophytes (Bellaud 2009).

### 5.2.5 Sediment agitation

Mechanical devices like weed rollers, lake sweepers and beach groomers mechanically disturb the lake bottom within a well-defined area to remove aquatic plants and prevent regrowth. The machines sweep, roll, or drag repetitively over plants and the sediment. They must be attached to a post, dock or other structure and require a source of electricity. This method may dislodge plant fragments that could spread to new areas or re-colonize the same area when the agitation device is not in use.

### 5.2.6 Dredging

Dredging is usually not performed solely for aquatic plant management (Madsen 2000). It is more often used to deepen lakes subjected to sediment infill, remove high-nutrient surface sediments, increase the volume of the pelagic and hypolimnetic zones, or remove toxic substances (Peterson 1982). Lakes that are shallow due to sedimentation typically have abundant aquatic plant growth. Dredging reduces aquatic plant problems directly by removing the plants, bottom sediment, and associated nutrients.

Dredging for aquatic plant control is most effective when the depth is increased to exceed the maximum depth of colonization (Collett et al. 1981, Tobiessen et al. 1992). Shallow dredging (one meter) has been found to be effective for a few months (Engel and Nichols 1984).

Dredging is effective when nutrient-rich sediments are removed and when the increased depth decreases the light available for plant photosynthesis and growth.

Dredging has several drawbacks. It produces high turbidity due to suspended sediments and can harm benthic organisms and other wildlife that overwinter in the sediments. It also has extensive permitting issues, high costs, and sediment disposal issues.

### 5.2.7 Shading/Light Attenuation

Use of aquatic dyes or surface covers can effectively limit light and restrict submersed aquatic plant growth. Both dye applications and shading covers are non-selective processes and thus control growth of native and introduced plants and algae. Commercially formulated natural or synthetic aquatic dyes are considered non-toxic to aquatic animals. They are generally used in small water bodies where outflow can be controlled, such as ornamental ponds or golf-course water hazards (Gettys et al. 2009).

Surface covers made of fabric or plastic can be installed to control plant growth; these may be held above or just below the surface. Covers are typically used only on small scale control projects, like boat docks or narrow streams or canals (Nichols 1991).

## 5.3 Biological Control

Biological control involves the intentional release of one species in an effort to control another species. Biological control agents undergo rigorous screening on a large suite of plants including the target and its relatives. Testing includes feeding specificity (including choice/no choice and exploratory feeding) as well as the agent's ability to complete its life cycle on plants other than the target (McFadyen 1998).

Insects are commonly used in biocontrol because their coevolutionary relationship with plants has led to highly species-specific relationships, but pathogens and animals are used as well. Establishment of biocontrol agents may be complicated by source-population climate tolerances as well as by parasitism and predation by native insects, fish or other animals. Some macrophytes are also chemically or structurally resistant to herbivory. Most agents have provided insufficient control to be used as a stand-alone management tool, but they can be an important component of integrated pest management strategies.

A variety of insect control agents have been released in the U.S. for control of aquatic plants, including the salvinia weevil (*Cyrtobagous salviniae*) alligator weed flea beetle (*Agasicles hygrophila*), mottled water hyacinth weevil (*Neochetina eichhorniae*), and most recently a water hyacinth plant hopper (*Megamelus scutellaris*). Milfoil weevil (*Euhrychiopsis lecontei*) is apparently an endemic weevil to North America that has emerged as an effective control of Eurasian milfoil (*Myriophyllum spicatum*). In most cases, damage done by biological agents controls, but does not eradicate, plant populations. Insects may limit vegetative propagules and their feeding scars or entry holes can facilitate secondary damage by naturally occurring pathogens (Gettys et al. 2009).

The grass carp (*Ctenopharyngodon idella*), native to rivers of East Asia, was introduced into the U.S. in 1963 for submersed aquatic weed control (Guillory and Gasaway 1978). Although they exhibit some species preference, grass carp are a typically considered a generalist herbivore that can damage native aquatic plant communities. Triploid grass carp, which have a low probability of successful reproduction and are functionally sterile (Bronson 2008), were developed to limit natural reproduction and population size of the fish. Use of grass carp in aquatic plant control is complicated by difficulty in developing stocking plans; they often prefer native plants over IAPS and either supply inadequate control of weedy species or complete eradication of all submersed aquatic plants (Gettys et al. 2009).

## 5.4 Chemical Control

Aquatic herbicides are an effective and inexpensive IAPS management tool. For example, the state of Florida reduced the area of water hyacinth ( *Eichhornia crassipes*) infestation from a high of 51,000 ha in the 1960s to 2000 ha primarily using the herbicide 2,4-D(Schardt 1997). The use of aquatic herbicides, however, is often controversial. In the past 20 years, the use and review of herbicides has changed significantly to accommodate human and environmental health concerns; and no herbicide can be labeled for aquatic use if it is shown to have unreasonable adverse effects on human health or the environment (Gettys et al. 2009). Because of the unique characteristics of aquatic systems and the relatively small size of the aquatic herbicide market, there are a limited number of effective, EPA-approved herbicides currently available for aquatic use (Table 5-1).

**Table 5-1. Selected contact and systematic herbicides approved for aquatic use by the U.S. EPA, their mode of action, and comments on use (modified from Getty's et al. 2009).**

| | Primary use | | | |
|---|---|---|---|---|
| **Compound** | **Submersed** | **Floating** | **Emergent** | **Mode of action** |
| Copper | X | X | | Contact, plant cell toxicant |
| Endothall | X | X | | Contact, inhibits respiration and protein synthesis |
| Diquat | X | X | X | Contact, inhibits photosynthesis and destroys cell membranes |
| Carfentrazone | | X | X | Contact, inhibits plant specific enzyme |
| 2,4-D | X | X | X | Systematic, plant growth regulator |
| Triclopyr | X | X | X | Systematic, plant growth regulator |
| Glyphosate | | X | X | Systematic, plant enzyme inhibitor |
| Imazapyr | | | X | Systematic, plant enzyme inhibitor |
| Fluridone | X | X | | Sytematic, plant enzyme inhibitor |
| Penoxsulam | X | X | | Sytematic, plant enzyme inhibitor |
| Imazamox | X | X | X | Sytematic, plant enzyme inhibitor |

There are positive and negative aspects to use of herbicides for aquatic plant management. Modern application technology focuses on matching contact time and chemical concentration in the water to the target species to allow for selective control. Used appropriately, systemic herbicides can selectively remove IAPS without major, long-term impacts on native plant communities. When used inappropriately aquatic herbicides can lead to nontarget impacts on native plants, fish, and invertebrates and development of herbicide tolerance in IAPS. Effective permitting and proper training of applicators can alleviate problems with aquatic herbicides.

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## References


Bell, C. E., C. A. Wilen, and A. E. Stanton. 2003. Invasive plants of horticultural origin. Hortscience **38**:14-16.

Bellaud, M. 2009. Chapter 6: Cultural and physical control of aquatic weeds. Page 210 *in* L. A. Gettys, W. T. Haller, and M. Bellaud, editors. Biology and control of aquatic plants: a best management practices handbook. Aquatic Ecosystem Restoration Foundation, Marietta, GA.

Boyd, C. E. 1987. Evapotranspiration/evaporation (E/Eo) ratios for aquatic plants. J. Aquat. Plant Manage **25**:1-3.

Boylen, C. W., L. W. Eichler, and J. D. Madsen. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. Hydrobiologia **415**:207-211.

Brock, V. E. and M. Takata. 1956. A limnological resurvey of Fena River Reservoir, Guam, Marianas Islands. Division of Fish and Game, Board of Commissioners of Agriculture and Forestry.

Bronson, C. H. 2008. A Risk Analysis Pertaining to the Use of Triploid Grass Carp for the Biological Control of Aquatic Plants. Florida Department of Agriculture and Consumer Services, Tallahassee, FL.

Carpenter, S. R. and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. Aquatic botany **26**:341-370.

Catford, J. A., R. Jansson, and C. Nilsson. 2008. Reducing redundancy in invasion ecology by integrating hypotheses into a single theoretical framework. Diversity and Distributions **15**:22-40.

Champion, P. D. and J. S. Clayton. 2000. Border control for potential aquatic weeds: Stage 1. weed risk model. Science for Conservation:48.

Champion, P. D. and J. S. Clayton. 2001. Border control for potential aquatic weeds: Stage 2. Weed risk assessment. Science for Conservation:30.

Chytrý, M., L. C. Maskell, J. Pino, P. Pyšek, M. Vilà, X. Font, and S. M. Smart. 2008. Habitat invasions by alien plants: a quantitative comparison among Mediterranean, subcontinental and oceanic regions of Europe. Journal of Applied Ecology **45**:448-458.

Cofrancesco, Jr., A.F., D.R.Reaves, and D.E. Averett. Transfer of invasive species associated . with movement of military equipment and personnel. Legacy ERDC/EL TR-07-8.

Cohen, J., N. Mirotchnick, and B. Leung. 2007. Thousands introduced annually: the aquarium pathway for non-indigenous plants to the St Lawrence Seaway. Frontiers in Ecology and the Environment **5**:528-532.

Cole, T. G., M. C. Falanruw, C. D. MacLean, C. D. Whitesell, and A. H. Ambacher. 1987. Vegetation survey of the Republic of Palau. PSW Res. Bull. **22**.

Collett, L. C., A. J. Collins, P. J. Gibbs, and R. J. West. 1981. Shallow dredging as a strategy for the control of sublittoral macrophytes: a case study in Tuggerah Lakes, New South Wales. Marine and Freshwater Research **32**:563-571.

DoN. 2010. Final Environmental Impact Statement,Guam and CNMI Military Relocation: Relocating Marines from Okinawa, Visiting Aircraft Carrier Berthing, and Army Air and Missile Defense Task Force. Department of the Navy, Pearl Harbor, HI.

Drew, W. M., K. C. Ewel, R. L. Naylor, and A. Sigrah. 2005. A tropical freshwater wetland: III. Direct use values and other goods and services. Wetlands Ecology and Management **13**:685-693.

Engel, S. and S. A. Nichols. 1984. Lake sediment alteration for macrophyte control. Journal of Aquatic Plant Management **22**:38-41.

Falanruw, M. C., C. D. Whitesell, T. G. Cole, C. D. MacLean, and A. H. Ambacher. 1987. Vegetation Survey of Yap, Federated States of Micronesia. PSW Res. Bull. **21**.

Fang, R. and G. W. Staples. 1995. Convolvulaceae. Pages 271-325 *in* Z. Y. Wu and P. H. Raven, editors. Flora of China. Missouri Botanical Garden Press, St. Louis, MO.

Ganesan, S. 2008. Traditional oral care medicinal plants survey of Tamil Nadu. Natural Product Radiance **7**:166-172.

Gettys, L. A., W. T. Haller, and M. Bellaud. 2009. Biology and control of aquatic plants: a best management practices handbook. Aquatic Ecosystem Restoration Foundation, Marietta, GA.

Godshalk, G. L., R. G. Wetzel, and H. L. Golterman. 1977. Decomposition of macrophytes and the metabolism of organic matter in sediments.*in* H. L. Golterman, editor. Interactions between sediments and fresh water. Dr. W. Junk BV Publishers, The Hague.

Guillory, V. and R. D. Gasaway. 1978. Zoogeography of the grass carp in the United States. Transactions of the American Fisheries Society **107**:105-112.

Halstead, J. M., J. Michaud, S. Hallas-Burt, and J. P. Gibbs. 2003. Hedonic analysis of effects of a nonnative invader (Myriophyllum heterophyllum) on New Hampshire (USA) lakefront properties. Environmental Management **32**:391-398.

Horn, C. N. 2002. Pontederiaceae, pickerel-weed family. Pages 37-46 *in* F. o. N. A. E. Committee, editor. Flora of North America North of Mexico, New York and Oxford.

Kay, S. H. and S. T. Hoyle. 2001. Mail order, the Internet, and invasive aquatic weeds. Journal of Aquatic Plant Management **39**:88-91.

Keller, R. P. and D. M. Lodge. 2007. Species invasions from commerce in live aquatic organisms: problems and possible solutions. BioScience **57**:428-436.

Kueffer, C., C. C. Daehler, C. W. Torres-Santana, C. Lavergne, J. Y. Meyer, R. Otto, and L. Silva. 2010. A global comparison of plant invasions on oceanic islands. Perspectives in Plant Ecology, Evolution and Systematics **12**:145-161.

Lander, M. A. and C. P. Guard. 2003. Creation of a 50-year rainfall database, annual rainfall climatology, and annual rainfall distribution map for Guam. WERI Technical Report **102**.

Levine, J. M. and C. M. D'Antonio. 2003. Forecasting biological invasions with increasing international trade. Conservation Biology **17**:322-326.

MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ.

MacLean, C. D., T. G. Cole, C. D. Whitesell, M. V. Falanruw, and A. H. Ambacher. 1986. Vegetation survey of Pohnpei, Federated States of Micronesia. PSW Res. Bull. **18**.

Madsen, J. D. 2000. Advantages and disadvantages of aquatic plant management techniques. Lakeline **20**:22-34.

Maki, K. and S. Galatowitsch. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. Biological Conservation **118**:389-396.

Manner, H. I. 2008. Directions for long-term research in traditional agricultural systems of Micronesia and the Pacific Islands. Micronesica **40**:63-86.

McCullough, D. G., T. T. Work, J. F. Cavey, A. M. Liebhold, and D. Marshall. 2006. Interceptions of nonindigenous plant pests at U.S. ports of entry and border crossings over a 17-year period. Biological invasions **8**:611-630.

Muirhead, J. R., A. M. Bobeldyk, J. M. Bossenbroek, K. J. Egan, and C. L. Jerde. 2009. Estimating dispersal and predicting spread of nonindigenous species. Pages 103-125 *in* R. P. Keller, D. M. Lodge, M. A. Lewis, and J. F. Shogren, editors. Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy, and Management. Oxford University Press, New York, NY.

Nelson, S. and L. G. Eldredge. 1991. Distribution and status of introduced cichlid fishes of the genera Oreochromis and Tilapia in the islands of the South Pacific and Micronesia. Asian fisheries science **4**:11-22.

Newroth, P. R. 1985. A review of Eurasian water milfoil impacts and management in British Columbia.*in* Proceedings of the First International Symposium on watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society, Vancouver, BC.

Nichols, S. A. 1991. The interaction between biology and the management of aquatic macrophytes. Aquatic Botany **41**:225-252.

NOAA-CSC. 1995-present. Coastal Change Analysis Program (C-CAP) Regional Land Cover, Commonwealth of the Northern Mariana Islands (CNMI), Saipan, 2005. NOAA Coastal Services Center, Charleston, SC.

Peters, W. L., M. H. Meyer, and N. O. Anderson. 2006. Minnesota horticultural industry survey on invasive plants. Euphytica **148**:75-86.

Peterson, S. A. 1982. Lake restoration by sediment removal. Journal of the American Water Resources Association **18**:423-436.

PIER. 2010. Plant threats to Pacific Ecosystems.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics **52**:273-288.

Reichard, S. H. and P. White. 2001. Horticulture as a pathway of invasive plant introductions in the United States. BioScience **51**:103-113.

Rockwell, H. W. 2003. Summary of a Survey of the Literature on the Economic Impact of Aquatic Weeds, a report of the Aquatic Ecosystem Research Foundation. Marietta, GA.

Schardt, J. D. 1997. Florida aquatic plant survey report. Florida Department of Environmental Protection, Bureau of Aquatic Plant Management, Tallahassee, FL.

Simberloff, D. 2009. We can eliminate invasions or live with them. Successful management projects. Biological Invasions **11**:149-157.

Smith, A. C. 1979. Flora Vitiensis nova: A new flora of Fiji (spermatophytes only). National Tropical Botanical Garden, Lawai, HI.

Stemmermann, L. and F. Proby. 1978a. Inventory of wetland vegetation in the Caroline Islands, wetland plants. VTN Pacific for the U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu, HI.

Stemmermann, L. and F. Proby. 1978b. Inventory of wetland vegetation in the Caroline Islands, wetland vegetation types. VTN Pacific for the U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu, HI.

Strecker, A. L., P. M. Campbell, and J. D. Olden. 2011. The aquarium trade as an invasion pathway in the Pacific Northwest. Fisheries **36**:74-85.

Tobiessen, P., J. Swart, and S. Benjamin. 1992. Dredging to Control Curly-Leaved Pondweed: A Decade Later. Journal of Aquatic Plant Management **30**.

Van Nes, E. H., M. S. van den Berg, J. S. Clayton, H. Coops, M. Scheffer, and E. van Ierland. 1999. A simple model for evaluating the costs and benefits of aquatic macrophytes. Hydrobiologia **415**:335-339.

Wagner, W. L. and D. L. Herbst. 1995. Contributions to the flora of Hawaii.*in* N. L. Evenhuis and S. E. Miller, editors. Records of the Hawaii biological survey for 1994, part 2: notes. University of Hawai'i and Bishop Museum Press, Honolulu, HI.

Wagner, W. L., D. R. Herbst, and S. H. Sohmer. 1999. Manual of the Flowering Plants of Hawai'i, Vols. 1 and 2, Revised Edition. University of Hawai'i and Bishop Museum Press, Honolulu, HI.

WHO, W. H. O. 2003. Fact Sheet No. 134: Traditional medicine. Geneva, Switzerland.

Wilde, S. B., T. M. Murphy, C. P. Hope, S. K. Habrun, J. Kempton, A. Birrenkott, F. Wiley, W. W. Bowerman, and A. J. Lewitus. 2005. Avian vacuolar myelinopathy linked to exotic aquatic plants and a novel cyanobacterial species. Environmental Toxicology **20**:348-353.

Wong, M. F. and B. R. Hill. 2000. Reconnaissance of hydrology and water quality of Lake Susupe, Saipan, Commonwealth of the Northern Mariana Islands, 1990. Water Resources Investigations Report 00-4054:32.

Work, T. T., D. G. McCullough, J. F. Cavey, and R. Komsa. 2005. Arrival rate of nonindigenous insect species into the United States through foreign trade. Biological Invasions **7**:323-332.

Yang, R. Y., S. Lin, and G. Kuo. 2008. Content and distribution of flavonoids among 91 edible plant species. Asia Pac J Clin Nutr **17**:275-279.

Yeung, C. W. and M. F. Wong. 1999. Storage Capacity and Water Quality of Lake Ngardok, Babeldaob Island, Republic of Palau, 1996-98. Water Resources Investigations Report 99-4118:26.

**Appendix A. Aquatic (Y) and other plant species currently banned from import (X) and permitted for import (W) to the Micronesia region.**

| Scientific Name | Common Name | Aquatic | US Fed | US Hawaii " | CNMI | FSM (From outside of)‡ | FSM (From within ) ' | RMI ¤ | Guam • | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acacia mearnsii* (De Wild.) | black wattle | | | X | | | | | | |
| *Acaena novae-zelandica* Kirk | New Zealand bur | | | X | | | | | | |
| *Acroptilon repens* (L.) D. C. | Russian knapweed | | | X | | | | | | |
| *Aeschynomene indica* L. | Kat sola, Indian jointvetch | | | X | | | | | | |
| *Ageratina adenophora* (Spreng.) King & H. Rob. | croftonweed, Maui pamakani | | | X | | | | | | |
| *Ageratina riparia* (Regel) King & H. Rob. | creeping croftonweed, Hamakua pamakani | | | X | | | | | | |
| *Allium vineale* L. | wild garlic | | | X | | | | | | |
| *Allium vineale* ssp. *Compactum* L. (Thuill.) Coss. & Germ. | wild garlic | | | X | | | | | | |
| *Alocasia macrorrhiza* (L.) G. Don | taro/edible aroid | Y | | | | X | | | | ‡All except seed and tissue cultures |
| *Ananas* spp. | pineapple | | | X | | | | | | "All |
| *Andropogon bicornis* L. | West Indian foxtail | | | X | | | | | | |
| *Andropogon virginicus* L. | broomsedge | | | X | | | | | | |
| *Anredera cordifolia* (Ten.) Steenis | Madeira vine | | | X | | | | | | |
| *Anubias* spp. | | | | | | | | | X | •All |
| *Aponogeton* spp. L. f | | | | | | | | | X | •All |
| *Arachis hypogaea* L. | peanuts/groundnuts | | | | | X | | | | ‡All except seed |
| *Ardisia elliptica* Thunb. | shoebutton ardisia | | | X | | | | | | |
| *Azolla pinnata* R. Brown | mosquito fern, water velvet | Y | X | X | X | | | | | |
| *Bocconia frutescens* L. | plume poppy | | | X | | | | | | |
| *Brassica oleracea* L. | cauliflower | | | | | | | X | | ¤All seeds require permit. |
| *Brassica* spp. L. | cabbage | | | | | | | X | | ¤All seeds require permit. |
| *Cardaria pubescens* (C. A. Mey.) Jarmolenko | hairy whitetop | | | X | | | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

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|---|---|---|---|---|---|---|---|---|---|---|
| *Caulerpa taxifolia* (Vahl) C. Agardh | Mediterranean strain, killer algae | Y | X | X | X | | | | | |
| *Cereus hildmannianus* K. Schum. | | | | X | | | | | | |
| *Cereus uruguayanus* Kiesling | spiny tree cactus, Peruvian apple | | | X | | | | | | |
| *Chromolaena odorata* (L.) King & H. Rob. | siamweed, bitterbush | | | X | | | | | | |
| *Cirsium arvense* (L.) Scop. | Canada thistle | | | X | | | | | | |
| *Citropsis* spp. Swingle & Kellerm. | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Citrus* spp. L. | citrus | | | | | X | X | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. 'Fruit from areas where fruit flies other than *Bactrocera frauenfeldi* (Caroline or mango fly) occur. |
| *Clidemia hirta* var. *hirta* (L.) D. Don | Koster's curse | | | X | | | | | | |
| *Coccinia grandis* (L.) Voigt | ivy gourd | | | X | | | | | | |
| *Cocos* spp. L. | palms | | | | | X | X | | | ‡All except seeds, nuts, and pollen from areas approved by the Chief of Agriculture. 'Coconuts, except those from which the perianths (caps) have been removed and/or coconuts which have been dehusked and which have not sprouted. Betel nuts from areas where fruit flies other than *Bactrocera frauenfeldi* (Caroline or mango fly) occur. |
| *Coffea* spp. L. | coffee | | | | | X | | | | ‡All propagating material except seeds |
| *Colocasia esculenta* (L.) Schott | taro/edible aroid | Y | | | | X | | | | ‡All except seed and tissue cultures |
| *Convolvulus arvensis* L. | field bindweed | | | X | | | | | | |
| *Cortaderia jubata* (Lem.) Stapf | | | | X | | | | | | |
| *Cryptocoryne* spp. Fisch. ex Wydl. | | Y | | | | | | | X | •All |
| *Cryptosperma chamissonis* Schott | taro/edible aroid | Y | | | | X | | | | ‡All except seed and tissue cultures |
| *Cymbopogon refractus* (R. Br.) A. Camus | barbwire grass | | | X | | | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

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|---|---|---|---|---|---|---|---|---|---|---|
| *Cyperus esculentus* L. | yellow nutsedge | Y | | X | | | | | | |
| *Cytisus monspessulanus* L. | French broom | | | X | | | | | | |
| *Cytisus scoparius* (L.) Link | Scotch broom | | | X | | | | | | |
| *Cytisus scoparius* var. *andreanus* (L.) Link (Puiss. Dippel) | Scotch broom | | | X | | | | | | |
| *Cytisus scoparius* var. *scoparius* (L.) Link | Scotch broom | | | X | | | | | | |
| *Dichrostachys cinerea* (L.) Wight & Am. | aroma | | | X | | | | | | |
| *Dichrostachys nutans* Benth. | marabu | | | X | | | | | | |
| *Dioscorea* spp. L. | yams | | | | | X | | | | ‡All except seed and tissue cultures |
| *Echinodorus* spp. except *E. cordifolius* Rich. ex Engelm. | | Y | | | | | | | X | •All |
| *Eichhornia azurea* (Swartz) Kunth | anchored water hyacinth, rooted water hyacinth | Y | X | X | X | | | | | |
| *Elephantopus mollis* Kunth | elephantopus, elephant's foot | | | X | | | | | | |
| *Elymus repens* (L.) Gould | | | | X | | | | | | |
| *Elytrigia repens* (L.) Desv. ex Nevski | quackgrass | | | X | | | | | | |
| *Emex spinosa* (L.) Campd. | spiny emex | | | X | | | | | | |
| *Eremocitrus* spp. Swingle | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Eriocereus martinii* (Labour.) Riccob. | moon cactus | | | X | | | | | | |
| *Euphorbia esula* L. | leafy spurge | | | X | | | | | | |
| *Fortunella* spp. Swingle | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Genista monspessulana* (L.) L. A. S. Johnson | | | | X | | | | | | |
| *Grevillea banksii* R. Br. | kahiliflower, Bank's grevillia | | | X | | | | | | |
| *Halogeton glomeratus* (M. Bieb.) C. A. Mey. | halogeton | | | X | | | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

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|---|---|---|---|---|---|---|---|---|---|---|
| *Harrisia martinii* (Labour.) Britton | | | | X | | | | | | |
| *Heliconia* spp. L. | heliconia | | | | | X | X | | | ‡'Plants, corms, and cut flowers except tissue cultures certified free from bunchy top disease, mosaic virus, Panama disease, and bacterial deseases including modo disease, black leaf streak, and Sigatoka disease |
| *Hydrilla verticillata* (L. f.) Royle | hydrilla | Y | X | X | X | | | | | |
| *Hygrophila polysperma* (Roxb.) T. Anderson | Miramar weed | Y | X | X | X | | | | | |
| *Hyptis pectinata* (L.) Poit. | comb hyptis | | | X | | | | | | |
| *Hyptis suaveolens* (L.) Poit. | wild spikenard | | | X | | | | | | |
| *Imperata cylindrica* (L.) P. Beauv. | cogon | | | X | | | | | | |
| *Ipomoea aquatica* Forsskal | water-spinach, swamp morning-glory | Y | X | X | X | | | | | |
| *Ipomoea batatas* (L.) Lam. | sweet potato | | | | | X | X | | | ‡All except pathogen tested tissue cultures and seed. 'All planting materials except tissue cultures are prohibited entry. |
| *Lagarosiphon major* (Ridley) Moss | oxygen weed | Y | X | X | X | | | | | |
| *Lagascea mollis* Cav. | acuate | | | X | | | | | | |
| *Lepidium latifolium* L. | perennial pepperweed | | | X | | | | | | |
| *Limnophila sessiliflora* (Vahl) Blume | ambulia | Y | X | X | X | | | | | |
| *Lycopersicon esulentum (Solanum lycopersicum)* Miller | tomato | | | | | X | | X | | ‡All except fruit and seed. ¤All seeds require permit. |
| *Malachra alceifolia* Jacq. | malachra | | | X | | | | | | |
| *Manihot esculenta* Crantz | tapioca/cassava | | | | | X | | | | ‡All except stems and tissue cultures from pathogen tested sources. 'All planting materials except tissue cultures are prohibited. |
| *Medinilla venosa* (Blume) Blume | | | | X | | | | | | |
| *Melaleuca quinquenervia* (Cav.) Blake | broadleaf paper bark tree | Y | X | X | X | | | | | |
| *Melastoma* L. | melastoma | | | X | | | | | | |
| *Miconia* Ruiz & Pav. | miconia | | | X | | | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

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|---|---|---|---|---|---|---|---|---|---|---|
| *Microcitrus* spp. Swingle | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Microsorium pteropus* | java fern | Y | | | | | | | X | •All |
| *Mikania micrantha* Kunth | mile-a-minute | | | X | | | | | | |
| *Mikania scandens* (L.) Willd. | climbing hempweed | | | X | | | | | | |
| *Mimosa diplotricha* C. Wright | giant sensitiveplant | | | X | | | | | | |
| *Mimosa invisa* Mart. ex Colla | giant sensitiveplant | | | X | | | | | | |
| *Mimosa pellita* Kunth ex Willd. | | | | X | | | | | | |
| *Mimosa pigra L.* | thorny sensitive plant | | | X | | | | | | |
| *Miscanthus floridulus* (Labill.) Warb. ex K. Schum. & Lauterb. | miscanthus, Japanese silvergrass | | | X | | | | | | |
| *Monanthocitrus* spp. Tanaka | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Monochoria hastata* (L.) Solms-Laubach | | Y | X | X | X | | | | | |
| *Monochoria vaginalis* (Burman f.) C. Presl. ex Kunth | | Y | X | X | X | | | | | |
| *Montanoa hibiscifolia* (Benth.) Strandl. | tree daisy | | | X | | | | | | |
| *Morella faya* (Aiton) Wilbur | | | | X | | | | | | |
| *Murraya* spp. J. Koenig ex L. | | | | | | X | | | | ‡All |
| *Myrica faya* Aiton | firetree, candleberry myrtle | | | X | | | | | | |
| *Nassella trichotoma* (Nees) Hack. | | | | X | | | | | | |
| *Ottelia alismoides* (L.) Pers. | | Y | X | X | X | | | | | |
| *Oxyspora paniculata* (D. Don) D. C. | | | | X | | | | | | |
| *Panicum repens* L. | torpedograss | | | X | | | | | | |
| *Passiflora bicornis* Mill. | | | | X | | | | | | |
| *Passiflora mollissima* (Kunth) L. H. Bailey | banana passionfruit, banaba poka | | | X | | | | | | |
| *Passiflora pulchella* Kunth | wingleaf passionfruit | | | X | | | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

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|---|---|---|---|---|---|---|---|---|---|---|
| *Passiflora tripartita* var. *mollissima* (Juss.) Poir. (Kunth) Holm-Niesen & P. M. Jørg. | | | | X | | | | | | |
| *Pennisetum setaceum* (Forssk.) Chiov. | fountaingrass | | | X | | | | | | |
| *Phaseolus* spp. | beans | | | | | X | | X | | ‡All parts except seeds. ¤All seeds require permit. |
| *Piper aduncum* L. | spiked pepper | | | X | | | | | | |
| *Piper* spp. L. | pepper | | | | | X | | | | ‡All except seed and tissue cultures |
| *Pittosporum undulatum* Vent. | Victorian box | | | X | | | | | | |
| *Pleurocitrus* spp. Tanaka | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Poncirus* spp. Raf. | citrus | | | | | X | | | | ‡All except fruit and seeds. Fruit from areas where citrus canker (*Xanthomonas campestris* p.v. *citri* ) occurs. |
| *Prosopis juliflora* (Sw.) D. C. | | | | X | | | | | | |
| *Pueraria phaseoloides* (Roxb.) Benth. | tropical kudzu | | | X | | | | | | |
| *Rhodomyrtus tomentosus* (Aiton) Hassk. | downy rosemyrtle | | | X | | | | | | |
| *Rubus argutus* Link | prickly Florida blackberry | | | X | | | | | | |
| *Rubus ellipticus* var. *obcordatus* Sm. Focke | yellow Himalayan raspberry | | | X | | | | | | |
| *Rubus niveus* Thunb. | hill raspberry | | | X | | | | | | |
| *Rubus sieboldii* Blume | Molucca raspberry | | | X | | | | | | |
| *Sagittaria sagittifolia* L. | arrowhead | Y | X | X | X | | | | | |
| *Salsola kali* L. | Russian thistle | | | X | | | | | | |
| *Salvinia auriculata* Aubl. | giant salvinia | Y | X | X | X | | | | | |
| *Salvinia biloba* Raddi | giant salvinia | Y | X | X | X | | | | | |
| *Salvinia herzogii* de la Sota | giant salvinia | Y | X | X | X | | | | | |
| *Salvinia molesta* D. S. Mitchell | giant salvinia | Y | X | X | X | | | | | |
| *Senecio madagascariensis* Poir. | fireweed | | | X | | | | | | |
| *Solanum carolinense* L. | horsenettle | | | X | | | | | | |
| *Solanum elaeagnifolium* Cav. | silverleaf nightshade | | | X | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| *Solanum robustum* Wendl. | | | | X | | | | | | |
| *Solanum tampicense* Dunal | wetland nightshade | Y | X | X | X | | | | | |
| *Solanum torvum* Sw. | turkeyberry, terongan | | | X | | | | | | |
| *Solanum tuberosum* L. | potato (Irish) | | | | | X | | | | |
| *Sonchus arvensis* L. | perennial sowthistle | | | X | | | | | | |
| *Sorghum* spp. Moench | sorghum | | | | | | | | | All except seed |
| *Sparganium erectum* L. | exotic bur-reed | Y | X | X | X | | | | | |
| *Spartium junceum* L. | Spanish broom | | | X | | | | | | |
| *Spathiphyllum tasson* | Brazil sword | Y | | | | | | | X | •All |
| *Stipa trichotoma* Ness | nasella tussock | | | X | | | | | | |
| *Striga* Lour. | witchweed | | | X | | | | | | |
| *Themeda villosa* (Poir.) A. Camus | Lyon's grass | | | X | | | | | | |
| *Theobroma cacao* L. | cacao | | | | | X | | | | ‡All except seeds from Asia Pacific Region |
| *Tibouchina* Aubl. | tibouchina | | | X | | | | | | |
| *Triumfetta rhomboidea* Jacq. | paroquet bur | | | X | | | | | | |
| *Triumfetta semitriloba* Jacq. | Sacramento bur | | | X | | | | | | |
| *Ulex europaeus* L. | gorse | | | X | | | | | | |
| *Urena lobata* L. | caesarweed | | | X | | | | | | |
| *Verbascum thapsus* L. | mullein | | | X | | | | | | |
| *Vesicularia dubyana* | java moss | Y | | | | | | | X | •All |
| *Xanthosoma sagittifolium* (L.) Schott | taro/edible aroid | Y | | | | X | | | | ‡All except seed and tissue cultures |
| *Zea mays* L. | maize/popcorn | | | | | X | | X | | ‡All except seed. ¤All seed require permit. |
| Areaceae | palms | | | | | X | X | | | ‡All except seeds, nuts, and pollen from areas approved by the Chief of Agriculture. 'Coconuts, except those from which the perianths (caps) have been removed and/or coconuts which have been dehusked and which have not sprouted. Betel nuts from areas where fruit flies other than *Bactrocera frauenfeldi* (Caroline or mango fly) occur. |

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|---|---|---|---|---|---|---|---|---|---|---|
| Brassicaceae | crucifers | | | | | | | X | | ¤All seeds require permit. |
| | | | | | | | | | | "Except genus *Ananas* : seeds, tissue cultured plants, and dried non-living |
| Bromeliaceae | | | | X | | | | | | materials require permit. |
| | | | | | | | | | | ‡'Plants, corms, and cut flowers except tissue cultures certified free from |
| | | | | | | | | | | bunchy top disease, mosaic virus, Panama disease, and bacterial deseases |
| Musaceae | banana, abaca | | | | | X | X | | | including modo disease, black leaf streak, and Sigatoka disease. |
| Heliconiaceae | | | | | | X | | | | |

Sources: U.S. Fed: USDA, Animal Plant Health Inspection Service. 2010.; Hawai'i= USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 11 May 2010). National Plant Data Center, Baton Rouge, LA 70874-4490 USA, Hawai'i Board of Agriculture, Amendments to Chapter 4-70 Hawai'i Administrative Rules. 2001.; FSM= National Government of the FSM, Plant and animal quarantine regulations. 2000.; RMI: The Government of the RMI, Ministry of Resources and Development. RMI Plants quarantine instructions and form.; Guam: Guam Department of Agriculture, Division of Aquatic and Wildlife Resources Permitted Plants List.

# Appendix B. Assessing the risk posed to Micronesia by invasive aquatic weeds

# Assessing the risk posed to Micronesia by invasive aquatic weeds


## Elements of the original document prepared by

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# Contents

# 1. Introduction

The freshwater resources of Micronesia and Hawaii are critically important to the human populations and natural ecosystems these waters support. Introduced invasive aquatic macrophytes, algae, and cyanobacteria represent an important threat to the integrity of these aquatic systems. Understanding the potential pathways and vectors by which these taxa may be introduced is essential for creating sound management strategies to minimize their introduction and spread in Micronesia and abroad.

The New Zealand National Institute of Water and Atmospheric Research Ltd (NIWA) was contracted by Portland State University (PSU) to prepare aquatic weed risk assessments for a range of species including those locally present on Micronesia (Guam, Northern Mariana Islands, Federated States of Micronesia and the Republic of Palau) or potentially imported from Hawaii, South East Asia (Philippines, Indonesia, Malaysia, Taiwan and Japan) or from other risk sources (mainland USA and Australia), which threaten ecological, social and economic values of Micronesia.

Weed risk assessment models have been developed to predict the invasiveness of potential new weeds to a country by quantifying biological and ecological traits of the plant, their geographical origin and previous introduction history. These models then provide a decision support tool to managers as a basis for future management actions. These may include determining which cultivated freshwater plants should be banned from entry (black list), prevented from deliberate dispersal through the nursery trade, targeted for control/eradication and conversely which species are suitable for importation and pose little threat to the country to which they are imported. Examples of weed risk assessment protocols and their use to manage weed species include Esler et al., (1993), Pheloung et al., (1999), Dahler et al., (2004), Champion (2005), Parker et al., (2007), Csurhes (2008) and IFAS (2010).

NIWA has developed a risk assessment model specifically for aquatic weeds - AWRAM (Champion & Clayton 2000; 2001), based on the failure of general weed risk assessment models (e.g., Pheloung et al., 1999; Daehler et al., 2004) to adequately discriminate the level of impact caused by aquatic plant species. These general models recognise that aquatic species often become weedy, giving an assessment score of 5 to any aquatic species (generally the questions answered in the assessment only score 1 or 2). Any species exceeding a threshold score of 6 is recommended for rejection by these models, and hence the vast majority of aquatic species evaluated exceed this threshold. Although aquatic species rank highly, there is little separation between species with differing levels of impact. For example, the submerged Hydrocharitacean weeds *Elodea canadensis, Lagarosiphon major, Egeria densa* and *Hydrilla verticillata* (all invasive alien species in New Zealand) were scored 24, 23, 23 and 22 respectively using the model of Pheloung et al., (1999). AWRAM scored 46, 60, 64 and 74 respectively, out of a total possible score of 152, reflecting their relative management importance (Champion & Clayton 2000).

AWRAM has been used to determine which aquatic species are prohibited for sale and distribution and to prioritise national eradication strategies in New Zealand (Champion 2005; Champion & Hofstra 2006). AWRAM has also been modified for other countries and used to recommend weed management initiatives in Australia, The U.S. states of Indiana and Florida, and potentially in Europe (Champion et al., in press; Petroeschevsky & Champion 2008; Gordon et al., 2010; Champion et al., 2010).

This report outlines the selection criteria used to select aquatic plant species prior to weed risk assessment and outlines a modified AWRAM used to score these species and identify the species of greatest concern.

# 2. Methods

## 2.1 Selection of species for assessment

Two field visits were undertaken by PSU and NIWA staff to identify aquatic plants, including introduced weeds either naturalised or in cultivation, and assess the range of freshwater aquatic habitats present on the following islands:

| | |
|---|---|
| Guam | 22-26 & 28 January; 19-20 April 2010. |
| Saipan, Northern Mariana Islands | 26 & 27 January 2010. |
| Pohnpei, Federated States of Micronesia | 22 & 23 April 2010. |
| Yap, Federated States of Micronesia | 25-27 April 2010. |
| Palau | 28 & 29 April 2010. |

The jurisdictions covered by the Micronesia Biosecurity Plan but not visited as part of this initiative include Kosrae, Chuuk, Marshall Islands, and Hawaii.

Plants were identified using a variety of literature including Cook (1996), Di Tomaso et al., (2003), Hussey et al., (2007), Koo et al., (2005), Lorence & Flynn (2009),Morita (1997), Sainty & Jacobs (2003), Sharpe (1986), Stephens & Dowling (2002) and Whistler, W.A. (1995). Habitat types were taken from Fosberg (1960), Falanruw (2002) and Ellison (2008).

A review of literature and web-based data was undertaken to:

- Determine the known distribution of aquatic plants in Micronesia.
- Identify risk species traded as aquarium and pond plants that could pose a threat to Micronesia.
- Identify the weed history and distribution of other risk species with an emphasis on species known to be present in Hawaii, South East Asia (including Philippines, Indonesia, Malaysia, Taiwan and Japan), mainland USA and Australia.

Distribution data for Micronesia were sourced from Fosberg et al., (1979; 1982; 1987), Lorence & Flynn (2009), Raulerson (2006), and the Hawaii Ecosystems at Risk (HEAR, 2010) and Pacific Islands Ecosystems at Risk (PIER) website.

A list of aquarium species permitted for importation into Guam was provided by Brent Tibbatts (Government of Guam, Department of Agriculture Division of Aquatic and Wildlife Resources) and these species were also assessed. A list of species traded internationally were collated based on Kasselmann (2003) and Champion & Clayton (2000; 2001).

Preliminary assessments of risk weeds, including aquatic species were compiled for Micronesia or various component states by Space et al., (2000a & b; 2003; 2009), Space & Falanruw (1999) and Meyer (2000). Aquatic weed species from adjacent areas were obtained from Barrett & Seaman (1980), Champion & Clayton (2000; 2001), Csurhes & Edwards (1998), Kadono (2004), Lancar & Krake (2002), Moody (1989), Pancho & Soerjan (1978), Parsons & Cuthbertson (2001), Pieterse & Murphy (1990), Staples et al., (2000) and Waterhouse (1993), with additional web-based resources HEAR (2010) Pacific Islands Ecosystems at Risk and ISSG (2010) Global Invasive Species Database, Invasive Species Specialist Group, IUCN.

A composite list of aquatic plants, mostly species, but in some cases genera or sub-specific taxa were compiled along with synonyms used in the literature, family affiliation and life-form type (Table 1). Life-form groups used were marginal (rarely growing in water), erect emergent, sprawling emergent, amphibious submerged, obligate submerged, free-floating and floating leaved - bottom rooted (water lily type). Table 2 compiles the known distribution of these taxa including additions to the flora found during the two field visits.

## 2.2 Aquatic weed risk assessment (AWRAM)

### 2.2.1 Information sources used for weed assessment

Over 100 references have been used to score the candidate weed species, ranging from specific papers on one aspect of a species ecology or management to general books on aquatic weed impacts or management. Table 3 gives the relevant information sources used for each taxon.

Two invaluable general references provide a valuable insight into the weed history of the potential aquatic weeds. Holm et al., (1979) reports the number of countries in which that weed is regarded as an economic weed. It is rather outdated and some serious weeds are either not recorded (e.g., *Cabomba caroliniana*) or underrepresented (e.g., *Mimosa pigra*) based on current information. Countries where the weed occurs are ranked (based on submissions from weed experts from each country) in 5 categories from highest to least impact:

- Serious – one of the 3 worst species.
- Principle – the next worst 10 species.
- Common.
- Present, but not widespread as a weed.

- Present in the flora but not assessed.

Randall (2002) and a web-accessible link (see Section 6) is essentially a catalogue of information on weedy species, with the number of references referring to that weed a good indication of its importance. Key words used to describe each species are:

- Agricultural weed.
- Environmental weed.
- Naturalized weed.
- Noxious weed.
- Cultivation escape (also with the term garden thug for some).
- Quarantine weed.
- Sleeper weed (or potential weed still in the lag phase of invasion).
- Unspecified weed.
- Casual alien.

Table 4 summarises information from the two references with the number of countries with each of the Holm et al., (1979) economic weed classifications, total number of Randall (2002) weed references (with tropical or sub-tropical references in parentheses), and Randall's (2002) weed classifications.

### 2.2.2 Weed risk assessment model

The weed risk assessment model used to score the species selected in Section 2.1, has three main component sections:

- Assessment of entry pathways to Micronesia, including the likely volume of propagules and likelihood of survival and successful establishment.
- Weed potential based on ecological versatility, competitive ability, reproductive output and dispersal mechanisms, ability to colonise undisturbed habitats and similarity of climate from source to new habitat.
- Impact based on types of impact on economic and social uses of water, environmental impacts, ease of management and weed history within indigenous and introduced ranges.

**Entry Pathways**

Potential weed sources and introduction routes to Micronesia are as follows:

- Present on N. Mariana Islands, FSM or Palau (internal spread).
- Present on Guam (most likely source of spread to other Micronesian islands).
- Present on Hawaii (most likely source of spread to Guam).
- Present in Philippines, Taiwan or Japan (most likely sources through military support personnel).
- Present in other SE Asian countries i.e., Indonesia, Malaysia, Thailand, Singapore, Vietnam (less likely sources of spread).
- Not in region but present in USA or Australia (even lower risk, but direct flights from Australia to Micronesia and Hawaii may alter risk profile).

Entry pathways from these sources are as follows:

- Aquarium trade of aquatic plants. Known importation to Guam is regulated, but importation of non-permitted species may occur through the mail services due to inability to inspect mail/courier from U.S. mainland. Mainland mail is likely the highest risk pathway at present due to the inability to appropriately inspect these items. Species with seeds or spores that resist desiccation and can be mailed may be particularly difficult to interdict.
- Trade in plant nurseries, markets and other sales of aquatic plants for ornamental use. This pathway is of slightly less risk because permits are required for importation and shipments are inspected.
- Food and medicinal plants introduced by various ethnicities associated with U.S. military build-up or otherwise (especially Philippines and Taiwan). It is likely that most high demand food plants (e.g., *Ipomoea aquatica*) have already been introduced into at least part of Micronesia or Hawaii but even these species may not be spread throughout the region and therefore appropriate protections both for the region and within the region should be in place to reduce the likelihood of their spread, either accidently or on purpose.
- Deliberate introduction to ‘improve’ fodder etc. (e.g., recommendation to Yap to import *Azolla* (M. Falanruw pers. comm.) and apparent introduction of *Salvinia molesta* from Australia to SE Asia to improve rice cultivation). Probably a low risk especially if the production of a blacklist of prohibited species will inform responsible agencies. But for most of the jurisdictions of

Micronesia these types of blacklist either do not currently exist or are in need of updating.

- Non-commercial ornamental spp. (e.g., plants imported from Philippines) brought in by individuals for their gardens/ponds etc. Another high risk pathway, although propagule pressure would be much less than the aquarium/nursery pathways.

- Contaminants or hitchhikers with other species that are permitted for sale (e.g., duckweeds (*Lemna*, *Landoltia* and *Spirodela*), *Utricularia* and *Azolla* spp.). This pathway also includes introductions through aquacultural shipments and transport. A low risk but requiring thorough inspection of imported material for these species.

- Contamination of U.S. military equipment from wetlands and aquatic sites overseas (*S. molesta* was spread in Australia from Queensland to Victoria (>1000 km) by military vehicles (authors pers. obs.). This would be a very low risk pathway because the only marsh area the U.S. military is planning to use in Micronesia is the cleaning station by Apra Harbor. Training exercises may take place in Hagoi lake/marsh on Tinian; however, the lake is mesohaline.

If a plant is already indigenous or naturalised within Guam or elsewhere in Micronesia it is assigned the maximum score of 30.

If cultivated in Micronesia then the number of propagules and likelihood of establishing a naturalised population is assessed as relatively high (see later).

If outside of the region, then the number of likely pathways is recorded; scoring 1 for each. For each pathway, the likely number of propagules (minimum 1 to maximum 10) and the likelihood of establishing a naturalised population (minimum 1 to maximum 10) are assigned. These are multiplied and then divided by 10 to give a maximum score of 10 for each pathway. The maximum score cannot exceed 30.

**Maximum Entry Pathway score = 30.**

**Weed potential**

The scores for this section approximately follow previous AWRAM models (Champion & Clayton 2000; Champion et al., 2008) with the scores of the following parameters based on characteristics of the species and the aquatic habitats available in Micronesia:

- Habitat versatility (maximum of 13)

- Range (minimum 1 to maximum 3), maximum if able to grow from aquatic to dry land, or from margin to > 5 m deep.
- Water level fluctuation (minimum 0 to maximum 3), maximum if able to tolerate one month dewatering.
- Nutrient (minimum 1 to maximum 2), maximum if able to tolerate high or low enriched waters.
- Shade tolerant (minimum 1 to maximum 3), maximum if able to grow from full sun to deep shade.
- Salinity (minimum 0 to maximum 2), maximum if able to grow in fully saline (35 ppt) water.

- Habitat range (maximum of 9)
  - Flowing water (minimum 0 to maximum 3), maximum if dominant in this habitat.
  - Still water (minimum 0 to maximum 3), maximum if dominant in this habitat.
  - Wetland with ephemeral standing water (minimum 0 to maximum 3), maximum if dominant in this habitat.
- Competitive ability (maximum of 20)
  - Within growth form (minimum 1 to maximum 16), maximum if excludes all other species (e.g., *Eichhornia crassipes, Hydrilla verticillata, Phragmites vallatoria*).
  - Between growth form (minimum 0 to maximum 4), maximum if excludes all other life-forms (e.g., tall emergent spp.).
- Propagule dispersal (maximum of 10)
  - Natural agents (minimum 0 to maximum 5), maximum if adapted for spread by waterfowl (e.g., *Najas* spp.- Agami & Waisel 1986) or wind (e.g., *Phragmites vallatoria*).
  - Accidental human spread (minimum 0 to maximum 5), maximum if spread by 3 methods (e.g., boat trailers, machinery, fishing nets).

    - Deliberate spread (minimum 0 to maximum 1), maximum if attractive to humans.
    - Effective dispersal within a water body (minimum 0 to maximum 1).
- Propagule output (maximum of 10)
    - Seed quantity (minimum 0 to maximum 3), maximum if >1000 seed produced /plant or $m^2$.
    - Seed viability/persistence (minimum 0 to maximum 2), maximum if viability > 1 year.
    - Clonal spread (minimum 0 to maximum 5), maximum if spreads by fragmentation.
- Establishment (maximum of 5).
    - Existing vegetation (minimum -5 to maximum 0), maximum if able to invade unmodified vegetation.
    - Disturbance (minimum 0 to maximum 5), maximum if able to aggressively colonise following vegetation clearance, newly constructed water bodies or nutrient enrichment.
- Suitable climate (minimum 0 to maximum of 5), maximum if source and destination have same climate.

**Maximum Weed Potential score = 72.**

**Impact**

These scores follow previous AWRAM models (Champion & Clayton 2000; Champion et al., 2008) with the following parameters scored:

- Obstruction (maximum of 10)
    - Recreation (minimum 0 to maximum 1), maximum if major nuisance.
    - Access (minimum 0 to maximum 2), maximum if major nuisance.
    - Flow (minimum 0 to maximum 1), maximum if major nuisance.
    - Irrigation (minimum 0 to maximum 5), maximum if able to prevent effective irrigation.

- Aesthetics (minimum 0 to maximum 1), maximum if visual and smell problems.

- Environmental damage (maximum of 10)

    - Biodiversity (minimum 0 to maximum 5), maximum if completely displace all other species.

    - Water quality (minimum 0 to maximum 3), maximum if deoxygenation/nutrient enrichment.

    - Physical processes (minimum 0 to maximum 2), maximum if promoting flooding or siltation.

- Other undesirable traits (maximum of 10)

    - Human health (minimum 0 to maximum 2), maximum if 2 impacts such as drowning risk, mosquito habitat, thorns, etc.

    - Agricultural weed (minimum 0 to maximum 8), maximum if major impact on taro culture.

- Resistance to management (maximum of 10)

    - Ease of implementation (minimum 0 to maximum 2), maximum if dense impenetrable thickets.

    - Recognition (minimum 0 to maximum 1), maximum if cryptic (e.g., submerged spp.).

    - Control methods (minimum 0 to maximum 2), maximum if no control methods (e.g., deep water species, tolerant to available herbicides).

    - Effectiveness (minimum 0 to maximum 2), maximum if ineffective (unable to reduce impact).

    - Duration (minimum 0 to maximum 2), maximum if no control >1 month.

- Weed history (maximum of 10)

    - Indigenous range (minimum 1 to maximum 5), maximum if serious or principle weed of many tropical/sub-tropical countries.

    - Invasive alien range (minimum 0 to maximum 5), maximum if serious or principle weed of many tropical/sub-tropical countries.

**Maximum Impact score = 50.**

Thus the maximum and minimum theoretical scores would be:

| Component | Maximum | Minimum |
|---|---|---|
| • Entry | 30 | 1 |
| • Weed potential | 72 | 0 |
| • Impact | 50 | 1 |
| • **Total** | **152** | **2** |

- Presentation of AWRAM results

Table 5 and 6 present the weed risk assessment scores for the 95 taxa. Table 5 presents the taxa ranked on total AWRAM score, also listing component Entry, Weed potential and Impact scores and combined Weed potential and Impact scores. Table 6 presents the taxa ranked on combined Weed potential and Impact scores and also presents the habitat types where it is likely to grow.

Habitat types discerned on the field trips can be divided into seven groups:

- Shaded 'jungle' streams and rivers.
- Open drains, streams and rivers.
- Reservoirs, ponds and natural lakes.
- Savannah wetlands.
- Lowland wetlands (e.g., *Phragmites vallatoria* dominated areas).
- Cultivated wetlands (e.g., taro cultivation – disturbed wetlands formerly dominated by *P. vallatoria*).
- Swamp forest.

# 3. Results

**Table 1:** List of species (or other taxa) assessed for weed potential in Micronesia, with synonyms used in recent literature, family and life-form (as - amphibious submerged;

ee - erect emergent; ff - free-floating; m – marginal, rarely growing in water; os - obligate submerged; se - sprawling emergent; wl - waterlily type).

| Name | Synonyms | Family | Life-form |
|---|---|---|---|
| *Actinoscirpus grossus* | *Scirpus grossus* | Cyperaceae | ee,m |
| *Aeschynomene aspera* | | Fabaceae | m |
| *Aeschynomene indica* | | Fabaceae | m |
| *Alternanthera philoxeroides* | | Amaranthaceae | se |
| *Anubias* spp. | | Araceae | as |
| *Aponogeton* spp. (excluding *A. distachyos)* | | Aponogetonaceae | os,fl |
| *Arundo donax* | | Poaceae | m,ee |
| *Azolla filiculoides* | | Salviniaceae | ff |
| *Azolla pinnata* | | Salviniaceae | ff |
| *Cabomba caroliniana* | | Cabombaceae | os |
| *Ceratophyllum demersum* | | Ceratophyllaceae | os |
| *Ceratopteris thalictroides* | *C. gaudichaudii* | Parkeriaceae | m,ff |
| *Cryptocoryne spp.* | | Araceae | as |
| *Cyperus involucratus* | | Cyperaceae | ee |
| *Cyperus prolifer* | | Cyperaceae | ee |
| *Echinodorus cordifolius* | | Alismataceae | ee |
| *Echinodorus* spp. (excluding *E. cordifolius)* | | Alismataceae | ee,as |
| *Egeria densa* | | Hydrocharitaceae | os |
| *Egeria najas* | | Hydrocharitaceae | os |
| *Eichhornia azurea* | | Pontederiaceae | ff |
| *Eichhornia crassipes* | | Pontederiaceae | os,fl |

| Name | Synonyms | Family | Life-form |
|---|---|---|---|
| *Gymnocoronis spilanthoides* | | Asteraceae | se |
| *Hanguana malayana* | | Hanguanaceae | m,ff |
| *Heteranthera reniformis* | | Pontederiaceae | se |
| *Hydrilla verticillata* | | Hydrocharitaceae | os |
| *Hydrocleys nymphoides* | | Limnocharitaceae[1] | fl |
| *Hydrocotyle bonariensis* | | Araliaceae[2] | se |
| *Hydrocotyle ranunculoides* | | Araliaceae[2] | se |
| *Hydrocotyle umbellata* | | Araliaceae[2] | se |
| *Hydrolea zeylanica* | | Hydroleaceae[3] | m |
| *Hygrophila difformis* | | Acanthaceae | se,as |
| *Hygrophila polysperma* | | Acanthaceae | as |
| *Ipomoea aquatica* | | Convolvulaceae | m,se |
| *Ischaemum polystachyum* | | Poaceae | m,se |
| *Landoltia punctata* | *Spirodela punctata* | Araceae[4] | ff |
| *Lemna aequinoctialis* | *L. perpusilla* | Araceae[4] | ff |
| *Limnobium spongia* | | Hydrocharitaceae | ff |
| *Limnobium stoloniferum* | | Hydrocharitaceae | ff |
| *Limnocharis flava* | | Limnocharitaceae | ee |
| *Limnophila sessiliflora* | | Plantaginaceae[5] | os |
| *Ludwigia adscendens* | | Onagraceae | se |
| *Ludwigia octovalvis* | | Onagraceae | m |
| *Ludwigia peploides* | | Onagraceae | se |
| *Ludwigia peruviana* | | Onagraceae | m,ee |
| *Lysimachia fortunei* | | Primulaceae | m |
| *Marsilea minuta** | | Marsileaceae | as,fl |
| *Marsilea quadrifolia* | | Marsileaceae | fl |
| *Melaleuca quinquenervia* | | Myrtaceae | m |

| Name | Synonyms | Family | Life-form |
|---|---|---|---|
| *Microsorium pteropus* | | Polypodiaceae | as |
| *Mimosa pigra* | | Fabaceae | m |
| *Monochoria hastata* | | Pontederiaceae | ee,ff |
| *Monochoria vaginalis* | | Pontederiaceae | ee,ff |
| *Myriophyllum aquaticum* | | Haloragaceae | se |
| *Myriophyllum spicatum* | | Haloragaceae | os |
| *Najas graminea* | | Hydrocharitaceae | os |
| *Najas guadalupensis* | | Hydrocharitaceae | os |
| *Najas indica* | | Hydrocharitaceae | os |
| *Najas marina* | | Hydrocharitaceae | os |
| *Nelumbo lutea* | | Nelumbonaceae | fl |
| *Nelumbo nucifera* | | Nelumbonaceae | fl |
| *Neptunia oleracea* | *N. prostrata, N. natans* | Fabaceae | se |
| *Neptunia plena* | | Fabaceae | se |
| *Nymphaea caerulea* | *N. stellata, N. nouchali* | Nymphaeaceae | fl |
| *Nymphaea elegans* | | Nymphaeaceae | fl |
| *Nymphaea lotus* | *N. pubescens* | Nymphaeaceae | fl |
| *Nymphaea mexicana* | | Nymphaeaceae | fl |
| *Nymphoides indica* | | Menyanthaceae | fl |
| *Ottelia alismoides* | | Hydrocharitaceae | os |
| *Panicum repens* | | Poaceae | se |
| *Persicaria minor* var. *procera* | *Polygonum minus* | Polygonaceae | m |
| *Phragmites vallatoria* | *P, karka* | Poaceae | ee,m |
| *Pistia stratiotes* | | Araceae | ff |
| *Pontederia cordata* var. *lanceolata* | | Pontederiaceae | ee |

| Name | Synonyms | Family | Life-form |
|---|---|---|---|
| *Potamogeton crispus* | | Potamogetonaceae | os |
| *Rotala rotundifolia* | | Lythraceae | as |
| *Sagittaria latifolia* | | Alismataceae | ee |
| *Sagittaria montevidensis* | | Alismataceae | ee |
| *Sagittaria platyphylla* | | Alismataceae | ee,as |
| *Sagittaria sagittifolia* | *S. trifolia* | Alismataceae | ee,as |
| *Salvinia cucullata* | | Salviniaceae | ff |
| *Salvinia minima* | | Salviniaceae | ff |
| *Salvinia molesta* | *S. auriculata* | Salviniaceae | ff |
| *Salvinia natans* | | Salviniaceae | ff |
| *Schinus terebinthifolius* | | Anacardiaceae | m |
| *Spathiphyllum tasson* | | Araceae | m |
| *Sphenoclea zeylanica* | | Sphenocleaceae[6] | m |
| *Spirodela polyrhiza* | | Araceae[4] | ff |
| *Stuckenia pectinata* | *Potamogeton pectinatus* | Potamogetonaceae | os |
| *Trapa* spp. (excluding *T. natans)* | | Lythraceae[7] | fl |
| *Typha angustifolia* | | Typhaceae | ee |
| *Typha latifolia* | | Typhaceae | ee |
| *Utricularia gibba* | *U. exoleta* | Lentibulariaceae | ff |
| *Utricularia inflata* | | Lentibulariaceae | ff |
| *Vallisneria asiatica* | | Hydrocharitaceae | os |
| *Vallisneria denseserratula* | | Hydrocharitaceae | os |
| *Vallisneria natans* | | Hydrocharitaceae | os |
| *Vesicularia dubyana* | | Hypnaceae | as |

* Formerly regarded as *M. crenata*, but now assigned to *M. minuta* (Whitten & Jacono 2009).
1 Previously Butomaceae.
2 Previously Apiaceae.
3 Previously Hydrophyllaceae.
4 Previously Lemnaceae.
5 Previously Scrophulariaceae.
6 Previously Campanulaceae.
7 Previously Trapaceae.

**Table 2:** List of species (or other taxa) assessed for weed potential in Micronesia, with their naturalised or indigenous distribution in Micronesia, or other countries where highest risk of introduction occurs. (Key to symbols used: Guam and N. Mariana Islands: G = Guam; S = Saipan; T = Tinian; R = Rota; P = Pagan. FSM and Palau: K = Kosrae; P = Pohnpei; C = Chuuk; Y = Yap; B = Palau. Southeast Asia: P = Philippines; I = Indonesia; M = Malaysia; T = Thailand; e = elsewhere).

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Actinoscirpus grossus* | | B[1] | | P,I,M,T,e | J | A | |
| *Aeschynomene aspera* | | | | P,I,M,T,e | | | |
| *Aeschynomene indica* | G | P | | P,I,M,T,e | J,T | A | U |
| *Alternanthera philoxeroides* | | | | | J | A | U |
| *Anubias* spp. | | | | | | | |
| *Aponogeton* spp. (excluding *A. distachyos)* | | | | I,T,e | | A | |
| *Arundo donax* | G | P,B | H | T,e | J,T | A | U |
| *Azolla filiculoides* | | | H | P,I,M,T,e | | | |
| *Azolla pinnata* | | | H[2] | P,I,M,T,e | J | A | U2 |
| *Cabomba caroliniana* | | | | P,e[3] | J,T | A | U |
| *Ceratophyllum demersum* | G[4] | | H | P,I,M,T,e | J,T | A | U |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Ceratopteris thalictroides* | G[5] | Y,B | H | P,I,M,T,e | J,T | A | U |
| *Cryptocoryne* spp. | | | | E | | | U6 |
| *Cyperus involucratus* | G | P,C,B | H | I,e | J | A | U |
| *Cyperus prolifer* | G[6] | | H | | | | U |
| *Echinodorus cordifolius* | G[6] | | H[2] | | | | U |
| *Echinodorus* spp. (excluding *E. cordifolius)* | G[6] | | | M,e | | | |
| *Egeria densa* | G[7] | | H | | J | A | |
| *Egeria najas* | | | | | | | |
| *Eichhornia azurea* | | | | P,e | J | A | U |
| *Eichhornia crassipes* | G,T,R | P,C,Y,B | H | P,I,M,T,e | J,T | A | U |
| *Gymnocoronis spilanthoides* | | | H[8] | | | A | |
| *Hanguana malayana* | | Y,B | | I,M,e | | | |
| *Heteranthera reniformis* | | | | E | | A | U |
| *Hydrilla verticillata* | G | | H | P,I,M,T,e | J,T | A | U |
| *Hydrocleys nymphoides* | | | H[9] | | J | A | U |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Hydrocotyle bonariensis* | | | | | | A | U |
| *Hydrocotyle ranunculoides* | | | | | | A | U |
| *Hydrocotyle umbellata* | | | | | | | U |
| *Hydrolea zeylanica* | | | | P,I,M,T,e | T | A | |
| *Hygrophila difformis* | | | | E | | A | |
| *Hygrophila polysperma* | | | | T,e | | A | U |
| *Ipomoea aquatica* | G,S,T,R,P | K,P,C,Y,B | H | P,I,M,T,e | J,T | A | U |
| *Ischaemum polystachyum* | G,S,R | K,P,C,Y,B | | P,M | | | |
| *Landoltia punctata* | | | H | | | A | U |
| *Lemna aequinoctialis* | G,S,T | C,Y | | P,I,M,T,e | | A | |
| *Limnobium spongia* | | | | | | | U |
| *Limnobium stoloniferum* | | | | | J | | U |
| *Limnocharis flava* | | | | I,M,T,e | | A | U |
| *Limnophila sessiliflora* | G[10] | | | P,M,e | | | U |
| *Ludwigia adscendens* | | | | P,I,M,T,e | J,T | A | |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Ludwigia octovalvis* | G,S,T,R,P | K,P,C,Y,B | H | P,I,M,T,e | J,T | A | |
| *Ludwigia peploides* | | | | | | A | U |
| *Ludwigia peruviana* | | | | I | | A | U |
| *Lysimachia fortunei* | | | | | J,T | A | |
| *Marsilea minuta* | | | H[11] | P,I,M,T,e | | | U |
| *Marsilea quadrifolia* | | | | P,I,M,T,e | J,T | N[12] | U |
| *Melaleuca quinquenervia* | G | P,Y,B | | | | A | U |
| *Microsorium pteropus* | | | | E | | | |
| *Mimosa pigra* | | | | I,M,T,e | | A | U |
| *Monochoria hastata* | | | | I,M,T,e | | A | |
| *Monochoria vaginalis* | G[13] | | H | I,M,T,e | JT | A | U |
| *Myriophyllum aquaticum* | G[6] | | H | P,I,e | JT | A | U |
| *Myriophyllum spicatum* | | | H | E | JT | | U |
| *Najas graminea* | | | | P,I,M,T,e | JT | A | U |
| *Najas guadalupensis* | | | H | | | | U |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Najas indica* | | | | P,I | | | |
| *Najas marina* | | | H | I,T,e | JT | A | U |
| *Nelumbo lutea* | | | | | | | U |
| *Nelumbo nucifera* | G[6] | | H | P,I,M,T,e | JT | A | U |
| *Neptunia oleracea* | | | H[8] | P,I,M,T,e | J | A | U |
| *Neptunia plena* | | | | I,M,e | | A | U |
| *Nymphaea caerulea* | G | P,B | H | I,M,T,e | J | A | U |
| *Nymphaea elegans* | G | | | | | A | U |
| *Nymphaea lotus* | G | | H | I,M,T,e | J | A | U |
| *Nymphaea mexicana* | | | | | | A | U |
| *Nymphoides indica* | | B[14] | | I,M,T,e | | A | U |
| *Ottelia alismoides* | | | | I,M,T,e | T | A | U |
| *Panicum repens* | S | B[15] | H | I,M,T,e | J,T | A | U |
| *Persicaria minor* var. *procera* | G | C,Y,B | | | | A | U |
| *Phragmites vallatoria*[16] | G,S,T,R,P | K,P,C,Y,B | | T,e | | A | |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Pistia stratiotes* | G,R | P[13],Y[17] | H | I,M,T,e | JT | A | U |
| *Pontederia cordata* var. *lanceolata* | | | | | J | A | U |
| *Potamogeton crispus* | | | | P,I,T,e | J,T | A | U |
| *Rotala rotundifolia* | | | | T,e | J,T | A | U |
| *Sagittaria latifolia* | G[6] | | H | N[18] | | | U |
| *Sagittaria montevidensis* | | | | | | A | U |
| *Sagittaria platyphylla* | | | | I | | A | U |
| *Sagittaria sagittifolia* | | | | I,M,T,e | T | | |
| *Salvinia cucullata* | G[6] | | | M,T,e | | | |
| *Salvinia minima* | | | | | | | U |
| *Salvinia molesta* | | | H | P,I,M,T,e | J | A | U |
| *Salvinia natans* | G[13] | | | I,M,e | J,T | | U |
| *Schinus terebinthifolius* | G | | H | | J | A | U |
| *Spathiphyllum tasson* | | | | | | | |
| *Sphenoclea zeylandica* | | | | P,I,M,T,e | T | | U |

| Name | Guam and N Marianas | FSM and Palau | Hawaii | Southeast Asia | Japan/Taiwan | Australia | Mainland USA |
|---|---|---|---|---|---|---|---|
| *Spirodela polyrhiza* | G[6] | | H | P,I,M,T,e | J,T | A | U |
| *Stuckenia pectinata* | | | H | e | J,T | A | U |
| *Trapa* spp. (excluding *T. natans)* | | | | e | J,T | | |
| *Typha angustifolia* | | | | P,I,M,T,e | J,T | | U |
| *Typha latifolia* | | | H | P,e | J,T | A | U |
| *Utricularia gibba* | | B | H | P,I,M,T,e | J | A | U |
| *Utricularia inflata* | | | | | J | | U |
| *Vallisneria* spp | | | H | P,I,M,T,e | J,T | A | U |
| *Vesicularia dubyana* | Likely to be widespread within SE Asia and Pacific Islands | | | | J | A | U |

1 Possibly present at Lake Ngardok.
2 First identified on Hawaii as part of this project.
3 Only reference to this distribution Lancar & Krake (2002).
4 Recorded as native by Fosberg et al., (1979), found in cultivation on Guam.
5 Guam plants sometimes regarded as the endemic *C. gaudichaudii* (Masuyama 2008).
6 First identified in cultivation on Guam as part of this project.
7 Reported from Guam, but name misapplied to *Hydrilla verticillata* (Fosberg et al., 1987).
8 Reported once from Hawaii, material destroyed (HEAR 2010).
9 In cultivation, Manoa University Campus.
10 Recorded as native by Fosberg et al., (1979).
11 Formerly regarded as *M. crenata*, but now assigned to *M. minuta* (Whitten & Jacono 2009).
12 *M. quadrifolia* misapplied to *M. mutica* in Australia.
13 Reported as naturalized as part of this project.
14 *Nymphoides* sp. recorded as present on Palau by Fosberg et al., (1979).
15 Found on Babeldaob as part of this project; only previously reported from Koror (Fosberg et al., 1987).
16 This species is likely native throughout the Mariana Islands
17 Reported in cultivation (M. Falanruw pers. comm.) but not seen by authors.
18 Reported as *S. latifolia* in error from SE Asia. Plants referred to as *S. trifolia* are synonymous with *S. sagittifolia*.

**Table 3:** References used to carry out weed risk assessments on potential weeds of Micronesia (numbers refer to references as in Section 5).

| Name | References |
|---|---|
| *Actinoscirpus grossus* | 19,27,40,43,64,69,70,76,96,97,99,107 |
| *Aeschynomene aspera* | 26*,27,33,43,64,84,99 |
| *Aeschynomene indica* | 26*,27,40,42,43,46,62,64,77,99 |
| *Alternanthera philoxeroides* | 3,8,11,13,18,28,30,31,40,42,43,48,50,53,54,64,69,71,77,98,103 |
| *Anubias* spp. | 51 |
| *Aponogeton* spp. (excluding *A. distachyos)* | 27,43,51,62,64,69,77 |
| *Arundo donax* | 11,20,26,28,40,43,48,61,64,71,92,98 |
| *Azolla filiculoides* | 5,9,18,28,30,40,43,49,50,51,64,67,92,98 |
| *Azolla pinnata* | 4,13,33,40,42,43,48,50,51,62,64,67,69,98,99,102 |
| *Cabomba caroliniana* | 3,8,13,14,18,28,30,40,48,50,51,57,67,102,104 |
| *Ceratophyllum demersum* | 5,11,13,16,28,31,33,40,43,44,48,51,62,64,69,76,77,92,96, 98 |
| *Ceratopteris thalictroides* | 44,51,59,62,64,67,69,76,97,98 |
| *Cryptocoryne* spp. | 51,67,69,98 |
| *Cyperus involucratus* | 26,40,92,98 |
| *Cyperus prolifer* | 67,92,98 |
| *Echinodorus cordifolius* | 24,43,51 |
| *Echinodorus* spp. (excluding *E. cordifolius)* | 5,28,51,64,98 |
| *Egeria densa* | 6,7,8,9,11,12,13,16,18,28,30,31,40,43,48,50,51,67,71,75,92,98,102,109 |
| *Egeria najas* | 6,7,12,51,75,85 |
| *Eichhornia azurea* | 4,8,12,14,43,50,51,58,64,67,98 |
| *Eichhornia crassipes* | 8,9,11,13,16,18,19,27,28,30,31,40,41,43,44,48,50,51,53,61,62,64,67,69,71,76,77,84,92,96,97,98,99,102 |
| *Gymnocoronis spilanthoides* | 8,9,11,13,30,31,40,43,48,50,51,70,71,107 |
| *Hanguana malayana* | 19,64,69 |
| *Heteranthera reniformis* | 8,12,23,40,43,51,64 |
| *Hydrilla verticillata* | 3,4,9,11,13,16,18,27,28,30,31,33,40,41,42,43,48,51,53,61, 62,64,67,69,76,86,92,96,97,98,99,102 |

**Name** **References**

| | |
|---|---|
| *Hydrocleys nymphoides* | 11,12,31,50,51,67,92,98 |
| *Hydrocotyle bonariensis* | 40,43,46 |
| *Hydrocotyle ranunculoides* | 3,12,18,28,30,40,43,46,50,51,81 |
| *Hydrocotyle umbellata* | 28,43 |
| *Hydrolea zeylanica* | 40,43,64,69 |
| *Hygrophila difformis* | 12,27,51,64 |
| *Hygrophila polysperma* | 4,9,12,26,27,30,40,48,51,64,67,98,102 |
| *Ipomoea aquatica* | 4,27,40,42,43,48,62,67,69,76,77,92,98 |
| *Ischaemum polystachyum* | 27*,40,48,64 |
| *Landoltia punctata* | 28,43,48,50,67,92,102 |
| *Lemna aequinoctialis* | 40,43,49,53,62,64,69,92 |
| *Limnobium spongia* | 12,22,28,43,51,102 |
| *Limnobium stoloniferum* | 12,22,28,50,51,67 |
| *Limnocharis flava* | 8,19,40,43,48,64,69,70,74,76,96,97,99 |
| *Limnophila sessiliflora* | 4,9,12,27,28*,43,48,51,62,64,67,77,98,102 |
| *Ludwigia adscendens* | 27,33,40,42,43,62,64,69,77,97,99 |
| *Ludwigia octovalvis* | 40,42,43,67,69,96,97,99 |
| *Ludwigia peploides* | 3,5,11,13,18,28,30,43,67,98 |
| *Ludwigia peruviana* | 8,12,13,14,24,40,43,48,64,69,71,76,98 |
| *Lysimachia fortunei* | 26,40,43,45 |
| *Marsilea minuta* | 10,40,43,51,62,64,67,69,70,96,97,98,99,101 |
| *Marsilea quadrifolia* | 10,40,42,43,51,64,67,76,98,99,102 |
| *Melaleuca quinquenervia* | 4,26,40,48,61,66,95,98 |
| *Microsorium pteropus* | 51 |
| *Mimosa pigra* | 3,4,8,26,33,40,43,48,62,64,67,69,80,96,99,105 |
| *Monochoria hastata* | 4,19,40,43,44,64,69,76,77,97,99 |
| *Monochoria vaginalis* | 4,5,28,40,43,44,53,62,64,67,69,76,92,96,98,99 |
| *Myriophyllum aquaticum* | 9,11,12,13,18,28,30,31,40,43,48,50,51,64,67,69,71,92,98, 102 |
| *Myriophyllum spicatum* | 8,12,13,14,28,40,41,42,43,48,62,64,67,69,98,108 |
| **Name** | **References** |

| | |
|---|---|
| *Najas graminea* | 5,28,40,42,43,62,64,67,69,97,98,99 |
| *Najas guadalupensis* | 5,12,14,28,40,43,51,92,98 |
| *Najas indica* | 51,64,69,96 |
| *Najas marina* | 1,14,28,40,42,43,51,67,92,98 |
| *Nelumbo lutea* | 12,43 |
| *Nelumbo nucifera* | 33,40,43,62,64,67,69,76,92,96,97,98 |
| *Neptunia oleracea* | 8,12,40,43,50,62,64,69,77 |
| *Neptunia plena* | 8,12,40 |
| *Nymphaea caerulea* | 27,40*,43,62,64,67,69,70,76,84,92,98 |
| *Nymphaea elegans* | 40* |
| *Nymphaea lotus* | 40*,43,51,62,64,67,69,97,98,99 |
| *Nymphaea mexicana* | 11,12,28,40*,43,67,98 |
| *Nymphoides indica* | 33,43,51,62,64,67,69,76,97,98 |
| *Ottelia alismoides* | 4,5,27,40,43,51,62,64,67,69,76,77,98,102 |
| *Panicum repens* | 13,14,40,43,44,48,61,64,66,67,69,76,77,96,97,98,99 |
| *Persicaria minor* var. *procera* | 28,40,43,64,98 |
| *Phragmites vallatoria* | 8,19,43,44,62,64,76 |
| *Pistia stratiotes* | 9,12,18,26,27,28,30,31,40,41,43,44,48,50,51,53,62,64,67,69,71,76,77,92,98,99,102 |
| *Pontederia cordata* var. *lanceolata* | 12,46,50,67 |
| *Potamogeton crispus* | 5,13,28,40,42,43,48,62,64,67,98,102 |
| *Rotala rotundifolia* | 24,40,43,47,51,64,67,70,97 |
| *Sagittaria latifolia* | 12,40,43,98 |
| *Sagittaria montevidensis* | 5,11,12,13,28,43,51,67,71,98 |
| *Sagittaria platyphylla* | 11,12,13,31,43,48,71 |
| *Sagittaria sagittifolia* | 4,11,12,14,40,42,43,48,64,69,76 |
| *Salvinia cucullata* | 12,40,44,43,51,64,69,70,74,76,97,99 |
| *Salvinia minima* | 12,28,43,48,67,98 |
| *Salvinia molesta* | 3,4,8,11,12,13,16,18,28,30,31,33,40,41,43,44,48,50,51,54,60,61,62,64,67,69,71,76,80,92,96,98,99,102,106 |

| Name | References |
|---|---|
| *Salvinia natans* | 12,40,43,44,64,69,74,76,98 |
| *Schinus terebinthifolius* | 8,24,26,40,43,48,61,66,92,98 |
| *Spathiphyllum tasson* | 26* |
| *Sphenoclea zeylandica* | 27,33,40,44,43,64,76,96,98,99 |
| *Spirodela polyrhiza* | 40,42,43,51,62,69,92 |
| *Stuckenia pectinata* | 5,28,40,42,43,51,62,64,98 |
| *Trapa* spp. (excluding *T. natans)* | 2,8,43,50,55,62,64,69,97,108 |
| *Typha angustifolia* | 5,19,28,42,43,64,67,69,98,99,102 |
| *Typha latifolia* | 8,11,12,13,14,26,28,40,42,43,48,64,71,98 |
| *Utricularia gibba* | 5,11,13,33,39,43,48,50,51,62,64,98 |
| *Utricularia inflata* | 12,39,43,50,67 |
| *Vallisneria* spp | 11,13,16,31,40,42,43,48,50,51,62,64,67,69,97 |
| *Vesicularia dubyana* | |

**Table 4:** Weed history for potential weeds of Micronesia, based on Holm et al., (1979), which reports the number of countries in which that weed is regarded as an economic weed (ranked in 5 categories from highest to least impact: serious, principle, common, present as a weed, present in the flora but not assessed); and Randall (2002) with the number of references referring to that weed (tropical or sub-tropical references in parentheses), and where a weed is classified g = agricultural, e = environmental, n = naturalized, x = noxious, c = cultivation escape, q = quarantine, s = sleeper weed, w = unspecified weed, c = casual alien).

| **Species** | **Holm - rankings** | **Randall – no. of references** | **Randall weed categories** |
|---|---|---|---|
| *Actinoscirpus grossus* | 0 4 2 3 0 | 12 (12) | g e w |
| *Aeschynomene aspera* | 5 3 3 17 1 | 27 (21) | g e n x w |
| *Aeschynomene indica* | 0 1 0 3 1 | 10 (9) | g n w |
| *Alternanthera philoxeroides* | 2 2 2 7 0 | 61 | g e n x c s w |
| *Anubias* spp. | 0 0 2 5 5 | 28 (17) | g e n x c w a |
| *Aponogeton* spp. (excluding *A. distachyos)* | 0 0 0 0 0 | 0 | 0 |
| *Arundo donax* | 0 1 0 1 0 | 3 | e q w |
| *Azolla filiculoides* | 0 1 2 5 0 | 12 (9) | g e n x c w a |
| *Azolla pinnata* | 0 2 1 12 0 | 29 (15) | g e n x s w |
| *Cabomba caroliniana* | 0 0 0 0 0 | 35 (6+) | g e n x c w a |
| *Ceratophyllum demersum* | 2 5 3 26 3 | 30 | g e n x c s w |
| *Ceratopteris thalictroides* | 0 2 2 11 1 | 20 (13) | g e n c w a |
| *Cryptocoryne* spp. | 0 0 0 0 0 | 4 | e n |
| *Cyperus involucratus* | 0 0 0 0 0 | 16 (6) | e n c w |
| *Cyperus prolifer* | 0 0 0 0 0 | 12 (6) | g e n c w |
| *Echinodorus cordifolius* | 0 0 0 1 0 | 8 (3) | e n c w |
| *Echinodorus* spp. (excluding *E. cordifolius)* | 0 0 0 0 0 | 3 | g e n c |
| *Egeria densa* | 0 3 0 4 0 | 54 | g e n x c w a |
| *Egeria najas* | 0 0 0 0 0 | 1 | w |
| *Eichhornia azurea* | 0 1 1 1 0 | 18 | a e n x w |
| *Eichhornia crassipes* | 14 8 8 20 6 | 89 | g e n x c s w a |
| *Gymnocoronis spilanthoides* | 0 0 0 1 0 | 22 | e n x c s w a |
| *Hanguana malayana* | 0 0 0 0 0 | 0 | 0 |
| *Heteranthera reniformis* | 0 0 0 1 0 | 7 (3) | g e n w |

| Species | Holm - rankings | Randall – no. of references | Randall weed categories |
|---|---|---|---|
| *Hydrilla verticillata* | 3 4 4 13 1 | 58 | g e n x c s w a |
| *Hydrocleys nymphoides* | 0 0 0 0 0 | 17 (3) | e n x c w a |
| *Hydrocotyle bonariensis* | 0 0 1 4 0 | 25 (9) | g e n c w |
| *Hydrocotyle ranunculoides* | 0 0 0 1 1 | 13 (3+) | g e n x c s w a |
| *Hydrocotyle umbellata* | 0 0 0 6 0 | 8 (2) | n x c w |
| *Hydrolea zeylanica* | 0 0 0 1 4 | 9 (8) | g n w |
| *Hygrophila difformis* | 0 0 0 0 0 | 4 | e n c s w |
| *Hygrophila polysperma* | 0 0 0 0 0 | 12 (3) | e n x c w |
| *Ipomoea aquatica* | 3 3 3 23 2 | 11 (6) | a e n x c w |
| *Ischaemum polystachyum* | 0 0 0 0 0 | 5 (5) | g e w |
| *Landoltia punctata* | 0 0 0 1 1 | 14 (6) | g e n x c w |
| *Lemna aequinoctialis* | 0 1 1 2 2 | 10 (7) | n q w |
| *Limnobium spongia* | 0 0 0 1 0 | 8 (2) | g e n x w |
| *Limnobium stoloniferum* | 0 0 0 0 0 | 4 (4) | n |
| *Limnocharis flava* | 3 0 1 1 1 | 16 (3+) | g e n x c w |
| *Limnophila sessiliflora* | 0 0 1 0 1 | 19 (12) | g e n c x |
| *Ludwigia adscendens* | 1 1 0 28 4 | 15 (8) | g e w |
| *Ludwigia octovalvis* | 0 2 0 31 1 | 25 (25) | g e n w |
| *Ludwigia peploides* | 0 0 1 0 0 | 41 (22) | g e n w |
| *Ludwigia peruviana* | 0 0 0 1 0 | 27 (8) | g e n x c w |
| *Lysimachia fortunei* | 0 0 1 0 0 | 4 (3) | g e n c s w |
| *Marsilea minuta* | 1 0 2 0 0 | 15 (10) | n w |
| *Marsilea quadrifolia* | 1 5 2 14 1 | 19 (11) | g e n w |
| *Melaleuca quinquenervia* | 0 0 0 0 0 | 30 (8+) | g e n x w |
| *Microsorium pteropus* | 0 0 0 0 0 | 0 | 0 |
| *Mimosa pigra* | 0 2 0 5 2 | 41 (25) | g e n c x w |
| *Monochoria hastata* | 2 3 1 3 0 | 15 (9) | g e n x w |
| *Monochoria vaginalis* | 6 4 1 5 1 | 21 (8+) | g e n x w |
| *Myriophyllum aquaticum* | 0 4 3 5 0 | 56 | g e n x c w |

| Species | Holm - rankings | Randall – no. of references | Randall weed categories |
|---|---|---|---|
| *Myriophyllum spicatum* | 2 3 3 22 2 | 52 | g e n x c w |
| *Najas graminea* | 0 4 3 14 1 | 18 (10) | g e n x c w |
| *Najas guadalupensis* | 0 1 0 0 0 | 16 (10) | g e n w a |
| *Najas indica* | 0 0 0 0 0 | 0 | g e n x c w |
| *Najas marina* | 0 0 0 21 1 | 18 (10) | 0 |
| *Nelumbo lutea* | 0 0 1 2 0 | 11 (3) | g e n c w |
| *Nelumbo nucifera* | 0 3 2 12 0 | 17 (8) | g e x w |
| *Neptunia oleracea* | 0 0 0 3 3 | 6 (4) | e n c w a |
| *Neptunia plena* | 0 0 0 0 0 | 6 (3) | g n w |
| *Nymphaea caerulea* | 0 2 0 21 1 | 19 (11) | e n w |
| *Nymphaea elegans* | 0 0 0 0 0 | 0 | g n q w |
| *Nymphaea lotus* | 0 3 0 21 1 | 19 (11) | g e n x c w |
| *Nymphaea mexicana* | 0 0 0 1 0 | 23 (5) | g e n c w |
| *Nymphoides indica* | 0 0 1 3 3 | 17 (15) | g e n w |
| *Ottelia alismoides* | 1 3 12 1 | 18 (11) | g e n w |
| *Panicum repens* | 8 3 5 10 3 | 19 (11) | g e n x w |
| *Persicaria minor* var. *procera* | 0 0 2 0 1 | 10 (5) | e n x q w |
| *Phragmites vallatoria* | 0 2 0 4 5 | 7 (6) | g n w |
| *Pistia stratiotes* | 4 11 4 25 2 | 52 | g e n w |
| *Pontederia cordata* var*. lanceolata* | 0 0 0 0 0 | 21 (7) | g e n x c s w a |
| *Potamogeton crispus* | 0 6 4 16 0 | 21 (9) | g e n x c w a |
| *Rotala rotundifolia* | 0 3 0 14 0 | 12 (2) | e n x c s w a |
| *Sagittaria latifolia* | 0 1 0 0 0 | 22 (14) | g e n c s w |
| *Sagittaria montevidensis* | 0 0 1 6 0 | 21 (5) | g n x c w a |
| *Sagittaria platyphylla* | 1 0 0 6 0 | 31 (11) | g e n x c s w |
| *Sagittaria sagittifolia* | 0 0 0 1 0 | 20 (5) | g e n x w a |
| *Salvinia cucullata* | 0 5 3 22 2 | 27 (12) | g e w |
| *Salvinia minima* | 0 2 2 2 0 | 14 (8) | e n w |
| *Salvinia molesta* | 4 5 2 4 5 | 44 | g e n x c w a |

| Species | Holm - rankings | Randall – no. of references | Randall weed categories |
|---|---|---|---|
| *Salvinia natans* | 0 5 4 8 1 | 17 (7) | g e n c w |
| *Schinus terebinthifolius* | 0 0 1 1 2 | 43 (28) | g e n x c w a |
| *Spathiphyllum tasson* | 0 0 0 0 0 | 0 | 0 |
| *Sphenoclea zeylandica* | 5 5 1 7 1 | 24 (20) | g e n w |
| *Spirodela polyrhiza* | 0 4 2 28 1 | 27 (12) | g e n x c w |
| *Stuckenia pectinata* | 2 3 0 27 0 | 21 (10) | g e n x c w a |
| *Trapa* spp. (excluding *T. natans)* | 0 0 1 27 0 | 2 (1) | e n w |
| *Typha angustifolia* | 1 7 3 42 0 | 19 (13) | g e n c w a |
| *Typha latifolia* | 1 6 5 26 1 | 21 (9) | g e n x c w |
| *Utricularia gibba* | 0 1 0 1 0 | 20 (7) | e n x s w |
| *Utricularia inflata* | 0 0 0 1 0 | 8 (5) | e n x w |
| *Vallisneria* spp. | 0 4 2 21 0 | 20 (6) | g e n c w a |
| *Vesicularia dubyana* | 0 0 0 0 0 | 0 | 0 |

**Table 5:** Aquatic weed risk assessment scores generated for potential weeds of Micronesia, sorted on total score, also showing likelihood of entry into Micronesia, weed potential and likely impact scores, and combination of weed potential and impact scores.

| Species | Total WRA score | Likelihood of entry score (max = 30) | Weed potential score (max = 72) | Impact score (max = 50) | WRA excluding entry score |
|---|---|---|---|---|---|
| *Eichhornia crassipes* | 127 | 30 | 59 | 38 | 97 |
| *Hydrilla verticillata* | 123 | 30 | 57 | 36 | 93 |
| *Pistia stratiotes* | 117 | 30 | 50 | 37 | 87 |
| *Panicum repens* | 115 | 30 | 47 | 38 | 85 |
| *Phragmites vallatoria* | 115 | 30 | 58 | 27 | 85 |
| *Ceratophyllum demersum* | 113 | 30 | 53 | 30 | 83 |
| *Schinus terebinthifolius* | 107 | 30 | 55 | 22 | 77 |
| *Melaleuca quinquenervia* | 107 | 30 | 56 | 21 | 77 |
| *Monochoria vaginalis* | 105 | 30 | 44 | 31 | 75 |
| *Ipomoea aquatica* | 98 | 30 | 40 | 28 | 68 |
| *Arundo donax* | 96 | 30 | 32 | 34 | 66 |
| *Hanguana malayana* | 96 | 30 | 50 | 16 | 66 |
| *Mimosa pigra* | 95 | 2 | 55 | 38 | 93 |
| *Azolla pinnata* | 93 | 24 | 46 | 23 | 69 |
| *Ischaemum polystachyum* | 92 | 30 | 43 | 19 | 62 |
| *Alternanthera philoxeroides* | 90 | 1 | 49 | 40 | 89 |
| *Salvinia molesta* | 90 | 2 | 50 | 38 | 88 |
| *Salvinia cucullata* | 87 | 12 | 46 | 29 | 75 |
| *Salvinia natans* | 86 | 30 | 40 | 16 | 56 |
| *Eichhornia azurea* | 85 | 5 | 53 | 27 | 80 |
| *Azolla filiculoides* | 85 | 24 | 39 | 22 | 61 |
| *Nelumbo nucifera* | 85 | 30 | 35 | 20 | 55 |
| *Utricularia gibba* | 84 | 30 | 39 | 15 | 54 |
| *Myriophyllum aquaticum* | 83 | 10 | 44 | 29 | 73 |

| Species | Total WRA score | Likelihood of entry score | Weed potential score | Impact score | WRA excluding entry score |
|---|---|---|---|---|---|
| *Myriophyllum spicatum* | 83 | 1 | 48 | 34 | 82 |
| *Typha angustifolia* | 83 | 2 | 51 | 30 | 81 |
| *Limnocharis flava* | 83 | 10 | 46 | 27 | 73 |
| *Spirodela polyrhiza* | 83 | 24 | 39 | 20 | 59 |
| *Nymphaea caerulea* | 83 | 30 | 37 | 16 | 53 |
| *Nymphaea lotus* | 83 | 30 | 37 | 16 | 53 |
| *Aeschynomene indica* | 82 | 30 | 24 | 28 | 52 |
| *Typha latifolia* | 80 | 2 | 49 | 29 | 78 |
| *Ceratopteris thalictroides* | 80 | 30 | 35 | 15 | 50 |
| *Ludwigia peruviana* | 79 | 2 | 50 | 27 | 77 |
| *Lemna aequinoctialis* | 79 | 30 | 36 | 13 | 49 |
| *Monochoria hastata* | 78 | 5 | 44 | 29 | 73 |
| *Limnophila sessiliflora* | 77 | 30 | 28 | 19 | 47 |
| *Nymphaea elegans* | 77 | 30 | 37 | 10 | 47 |
| *Ludwigia octovalvis* | 76 | 30 | 32 | 14 | 46 |
| *Gymnocoronis spilanthoides* | 74 | 1 | 48 | 25 | 73 |
| *Egeria densa* | 73 | 1 | 40 | 32 | 72 |
| *Najas graminea* | 72 | 2 | 46 | 24 | 70 |
| *Sagittaria sagittifolia* | 71 | 4 | 43 | 24 | 67 |
| *Sagittaria latifolia* | 71 | 10 | 42 | 19 | 61 |
| *Cyperus involucratus* | 70 | 30 | 26 | 14 | 40 |
| *Persicaria minus* var. *procera* | 69 | 30 | 26 | 13 | 39 |
| *Najas guadalupensis* | 68 | 2 | 45 | 21 | 66 |
| *Najas indica* | 66 | 2 | 46 | 18 | 64 |
| *Nymphaea mexicana* | 64 | 1 | 41 | 22 | 63 |
| *Sagittaria platyphylla* | 64 | 1 | 42 | 21 | 63 |
| *Najas marina* | 64 | 2 | 44 | 18 | 62 |
| *Cabomba caroliniana* | 63 | 1 | 37 | 25 | 62 |

| Species | Total WRA score | Likelihood of entry score | Weed potential score | Impact score | WRA excluding entry score |
|---|---|---|---|---|---|
| *Actinoscirpus grossus* | 63 | 2 | 37 | 24 | 61 |
| *Stuckenia pectinata* | 63 | 1 | 44 | 18 | 62 |
| *Sagittaria montevidensis* | 62 | 1 | 40 | 21 | 61 |
| *Landoltia punctata* | 62 | 12 | 35 | 15 | 50 |
| *Heteranthera reniformis* | 61 | 1 | 39 | 21 | 60 |
| *Limnobium stoloniferum* | 60 | 3 | 39 | 18 | 57 |
| *Ludwigia adscendens* | 60 | 2 | 45 | 13 | 58 |
| *Aeschynomene aspera* | 59 | 1 | 24 | 34 | 58 |
| *Neptunia oleracea* | 59 | 3 | 37 | 19 | 56 |
| *Ludwigia peploides* | 59 | 2 | 43 | 14 | 57 |
| *Nymphoides indica* | 59 | 3 | 43 | 13 | 56 |
| *Hydrocotyle ranunculoides* | 58 | 4 | 39 | 15 | 54 |
| *Neptunia plena* | 57 | 1 | 37 | 19 | 56 |
| *Vallisneria spp* | 56 | 1 | 34 | 21 | 55 |
| *Limnobium spongia* | 55 | 1 | 39 | 15 | 54 |
| *Trapa* spp. (excluding *T. natans)* | 53 | 2 | 34 | 17 | 51 |
| *Sphenoclea zeylandica* | 52 | 1 | 29 | 22 | 51 |
| *Vesicularia dubyana* | 52 | 30 | 22 | 0 | 22 |
| *Utricularia inflata* | 51 | 1 | 35 | 15 | 50 |
| *Hydrocleys nymphoides* | 50 | 2 | 32 | 16 | 48 |
| *Potamogeton crispus* | 50 | 1 | 33 | 16 | 49 |
| *Hygrophila polysperma* | 49 | 1 | 32 | 16 | 48 |
| *Egeria najas* | 49 | 1 | 35 | 13 | 48 |
| *Marsilea quadrifolia* | 48 | 1 | 31 | 16 | 47 |
| *Nelumbo lutea* | 48 | 1 | 35 | 12 | 47 |
| *Hydrocotyle bonariensis* | 48 | 4 | 34 | 10 | 44 |
| *Marsilea minuta* | 47 | 2 | 32 | 13 | 45 |
| *Hydrocotyle umbellata* | 47 | 4 | 33 | 10 | 43 |

| **Species** | **Total WRA score** | **Likelihood of entry score** | **Weed potential score** | **Impact score** | **WRA excluding entry score** |
|---|---|---|---|---|---|
| *Echinodorus cordifolius* | 46 | 3 | 28 | 15 | 43 |
| *Ottelia alismoides* | 46 | 1 | 33 | 12 | 45 |
| *Cyperus prolifer* | 44 | 5 | 26 | 13 | 39 |
| *Cryptocoryne* spp. | 43 | 2 | 31 | 10 | 41 |
| *Hydrolea zeylanica* | 42 | 1 | 30 | 11 | 41 |
| *Salvinia minima* | 41 | 1 | 33 | 7 | 40 |
| *Aponogeton* spp. (excluding *A. distachyos)* | 40 | 4 | 29 | 7 | 36 |
| *Pontederia cordata* var. *lanceolata* | 38 | 1 | 28 | 9 | 37 |
| *Echinodorus* spp. (excluding *E. cordifolius)* | 37 | 1 | 26 | 10 | 36 |
| *Lysimachia fortunei* | 35 | 5 | 23 | 7 | 30 |
| *Rotala rotundifolia* | 34 | 1 | 23 | 10 | 33 |
| *Hygrophila difformis* | 32 | 1 | 25 | 6 | 31 |
| *Anubias* spp. | 31 | 2 | 27 | 2 | 29 |
| *Microsorium pteropus* | 27 | 2 | 25 | 0 | 25 |
| *Spathiphyllum tasson* | 15 | 1 | 14 | 0 | 14 |

**Table 6:** Aquatic weed risk assessment scores generated for potential weeds of Micronesia, sorted on combined weed potential and impact scores, also showing likelihood of entry into Micronesia and total score, and potential habitats the species could threaten in Micronesia (1 = jungle streams; 2 = open streams; 3 = ponds; 4 = savanna wetlands; 5 = swamps; 6 = cultivated swamps; 7 = swamp forest).

| Species | Combined weed potential and impact score | Likelihood of entry score | Total WRA score | Habitat threatened |
|---|---|---|---|---|
| *Eichhornia crassipes* | 97 | 30 | 127 | 2 3 6 |
| *Hydrilla verticillata* | 93 | 30 | 123 | 1 2 3 4 |
| *Mimosa pigra* | 93 | 2 | 95 | 3 4 5 6 7? |
| *Alternanthera philoxeroides* | 89 | 1 | 90 | 2 3 6 |
| *Salvinia molesta* | 88 | 2 | 90 | 2 3 6 |
| *Pistia stratiotes* | 87 | 30 | 117 | 5 6 |
| *Panicum repens* | 85 | 30 | 115 | 2 3 6 |
| *Phragmites vallatoria* | 85 | 30 | 115 | 6 |
| *Ceratophyllum demersum* | 83 | 30 | 113 | 1 2 3 |
| *Myriophyllum spicatum* | 82 | 1 | 83 | 2 3 |
| *Typha angustifolia* | 81 | 2 | 83 | 2 3 5 6 |
| *Eichhornia azurea* | 80 | 5 | 85 | 3 |
| *Typha latifolia* | 78 | 2 | 80 | 2 3 5 6 |
| *Ludwigia peruviana* | 77 | 2 | 79 | 2 3 6 |
| *Melaleuca quinquenervia* | 77 | 30 | 107 | 3 4 5 6 |
| *Schinus terebinthifolius* | 77 | 30 | 107 | 3 4 5 6 |
| *Monochoria vaginalis* | 75 | 30 | 105 | 2 3 6 |
| *Salvinia cucullata* | 75 | 12 | 87 | 2 3 6 |
| *Gymnocoronis spilanthoides* | 73 | 1 | 74 | 2 3 6 |
| *Limnocharis flava* | 73 | 10 | 83 | 6 |
| *Monochoria hastata* | 73 | 5 | 78 | 2 3 6 |
| *Myriophyllum aquaticum* | 73 | 30 | 83 | 2 3 6 |
| *Egeria densa* | 72 | 1 | 73 | 2 3 |
| *Najas graminea* | 70 | 2 | 72 | 2 3 |
| *Azolla pinnata* | 69 | 24 | 93 | 2 3 4 |

| Species | Combined weed potential and impact score | Likelihood of entry score | Total WRA score | Habitat threatened |
|---|---|---|---|---|
| *Ipomoea aquatica* | 68 | 30 | 98 | 2 3 6 |
| *Sagittaria sagittifolia* | 67 | 4 | 71 | 2 3 6 |
| *Arundo donax* | 66 | 30 | 96 | 2 5 |
| *Hanguana malayana* | 66 | 30 | 96 | 2 3 |
| *Najas guadalupensis* | 66 | 2 | 68 | 2 3 |
| *Najas indica* | 64 | 2 | 66 | 2 3 |
| *Nymphaea mexicana* | 63 | 1 | 64 | 3 |
| *Sagittaria platyphylla* | 63 | 1 | 64 | 2 3 6 |
| *Cabomba caroliniana* | 62 | 1 | 63 | 2 3 |
| *Ischaemum polystachyum* | 62 | 30 | 92 | 6 |
| *Najas marina* | 62 | 2 | 64 | 2 3 |
| *Stuckenia pectinata* | 62 | 1 | 63 | 1 2 3 |
| *Actinoscirpus grossus* | 61 | 2 | 63 | 1 6 |
| *Azolla filiculoides* | 61 | 24 | 85 | 2 3 4 |
| *Sagittaria latifolia* | 61 | 10 | 71 | 2 3 6 |
| *Sagittaria montevidensis* | 61 | 1 | 62 | 2 3 6 |
| *Heteranthera reniformis* | 60 | 1 | 61 | 2 3 6 |
| *Spirodela polyrhiza* | 59 | 24 | 83 | 2 3 |
| *Aeschynomene aspera* | 58 | 1 | 59 | 6 |
| *Ludwigia adscendens* | 58 | 2 | 60 | 2 3 6 |
| *Limnobium stoloniferum* | 57 | 3 | 60 | 3 |
| *Ludwigia peploides* | 57 | 2 | 59 | 2 3 6 |
| *Neptunia oleracea* | 56 | 3 | 59 | 2 3 6 |
| *Neptunia plena* | 56 | 1 | 57 | 2 3 6 |
| *Nymphoides indica* | 56 | 3 | 59 | 3 |
| *Salvinia natans* | 56 | 30 | 86 | 2 3 6 |
| *Nelumbo nucifera* | 55 | 30 | 85 | 3 |
| *Vallisneria* spp. | 55 | 1 | 56 | 1 2 3 |

| Species | Combined weed potential and impact score | Likelihood of entry score | Total WRA score | Habitat threatened |
|---|---|---|---|---|
| *Hydrocotyle ranunculoides* | 54 | 4 | 58 | 2 3 6 |
| *Limnobium spongia* | 54 | 1 | 55 | 3 |
| *Utricularia gibba* | 54 | 30 | 84 | 2 3 4 |
| *Nymphaea caerulea* | 53 | 30 | 83 | 3 |
| *Nymphaea lotus* | 53 | 30 | 83 | 3 |
| *Aeschynomene indica* | 52 | 30 | 82 | 6 |
| *Sphenoclea zeylandica* | 51 | 1 | 52 | 6 |
| *Trapa* spp. (excluding *T. natans)* | 51 | 2 | 53 | 3 |
| *Ceratopteris thalictroides* | 50 | 30 | 80 | 3 6 |
| *Landoltia punctata* | 50 | 12 | 62 | 2 3 6 |
| *Utricularia inflata* | 50 | 1 | 51 | 2 3 |
| *Lemna aequinoctialis* | 49 | 30 | 79 | 2 3 6 |
| *Potamogeton crispus* | 49 | 1 | 50 | 2 3 6 |
| *Egeria najas* | 48 | 1 | 49 | 2 3 |
| *Hydrocleys nymphoides* | 48 | 2 | 50 | 2 3 |
| *Hygrophila polysperma* | 48 | 1 | 49 | 2 |
| *Limnophila sessiliflora* | 47 | 30 | 77 | 2 3 |
| *Marsilea quadrifolia* | 47 | 1 | 48 | 3 6 |
| *Nelumbo lutea* | 47 | 1 | 48 | 3 |
| *Nymphaea elegans* | 47 | 30 | 77 | 3 |
| *Ludwigia octovalvis* | 46 | 30 | 76 | 2 3 6 |
| *Marsilea minuta* | 45 | 2 | 47 | 3 6 |
| *Ottelia alismoides* | 45 | 1 | 46 | 3 |
| *Hydrocotyle bonariensis* | 44 | 4 | 48 | 2 3 6 |
| *Echinodorus cordifolius* | 43 | 3 | 46 | 2 3 6 |
| *Hydrocotyle umbellata* | 43 | 4 | 47 | 2 3 6 |
| *Cryptocoryne* spp. | 41 | 2 | 43 | 1 |
| *Hydrolea zeylanica* | 41 | 1 | 42 | 6 |

| Species | Combined weed potential and impact score | Likelihood of entry score | Total WRA score | Habitat threatened |
|---|---|---|---|---|
| *Cyperus involucratus* | 40 | 30 | 70 | 2 6 |
| *Salvinia minima* | 40 | 1 | 41 | 2 3 6 |
| *Cyperus prolifer* | 39 | 5 | 44 | 2 6 |
| *Persicaria minus* var. *procera* | 39 | 30 | 69 | 3 6 |
| *Pontederia cordata* var. *lanceolata* | 37 | 1 | 38 | 2 3 6 |
| *Aponogeton* spp. (excluding *A. distachyos)* | 36 | 4 | 40 | 1 2 3 4 |
| *Echinodorus* spp. (excluding *E. cordifolius)* | 36 | 1 | 37 | 2 3 6 |
| *Rotala rotundifolia* | 33 | 1 | 34 | 1 2 3 |
| *Hygrophila difformis* | 31 | 1 | 32 | 2 |
| *Lysimachia fortunei* | 30 | 5 | 35 | 2 3 |
| *Anubias* spp. | 29 | 2 | 31 | 1 |
| *Microsorium pteropus* | 25 | 2 | 27 | 1 |
| *Vesicularia dubyana* | 22 | 30 | 52 | 1 |
| *Spathiphyllum tasson* | 14 | 1 | 15 | 1 |

# 4. Discussion and recommendations

## 4.1 Dealing with uncertainty

As with any type of prediction, there is a degree of uncertainty regarding the validity of the weed risk assessment scores. In this case there are three main issues; identity of plant taxa, quality of weed records and lack of relevant information for non-weedy species.

There are problems with the identity of some taxa, e.g., the water lilies (*Nymphaea* species especially where these are of hybrid origin), and then relating this to weed information on these species in their naturalized or indigenous ranges. Where this confusion has occurred, taxa have been grouped (e.g., *N. nouchali* and *N. stellata* records have been grouped with *N. caerulea* and *N. pubescens* grouped with *N. lotus*). In the case where genera have historically had problematic taxonomy (e.g., *Vallisneria* and *Trapa*) all species weed information has been collated under that genus.

Ideally all information used to assess potential weeds would be based on scientifically validated data (i.e., peer-reviewed journals and other publications). However, much of the information is only available as 'grey' literature, and several of the primary references used for this weed risk assessment either use 'expert weed assessment' (Holm et al., 1977; 1979; 1997) or all available information regardless of validation (Randall 2002). Both of these approaches are seen as valid, with the resulting weed risk assessment information based on a wide collection and weight of information that major weed species should generate. This is evident from Tables 3 and 4, where the world renowned weeds such as *Eichhornia crassipes*, *S. molesta*, *Pistia stratiotes* and *Hydrilla verticillata* are represented by the greatest volume of references.

Conversely, information on potential weeds yet to show weedy characteristics, or those with limited weed potential, is often lacking. Champion et al., (2008) and Petroeschevsky & Champion (2008) regarded the lack of information on naturalization and weed impacts of aquarium and other ornamental species that were internationally traded in high volumes (therefore with high propagule pressure) over decades as a very good indication of lack of weed potential. Length of time and volume in the trade were scored negatively if a taxon had been traded for over 30 years without naturalising.

## 4.2 High ranked aquatic weeds

The top 12 AWRAM scores were assigned to species that were already naturalized, or native to at least some part of Micronesia (Table 5). Three native species were amongst the nine species with scores >100, comprising *Phragmites vallatoria*, a widespread and dominant wetland species, and also *Panicum repens* and *Ceratophyllum demersum*, both regarded as indigenous by Fosberg et a. (1979; 1987). These species were of very limited distribution, with only one site of *P. repens* seen during the field visits. Their indigenous status could be questioned. The remaining six species were all apparently limited in distribution, with the first record of *Monochoria vaginalis* in Micronesia and the first naturalized records of the highest and third-highest ranked species *E. crassipes* and *Pistia stratiotes* from Pohnpei made during field work contributing to this report. Of the 33 species scoring ≥ 80, ten were found or reported to be in cultivation in Micronesia, and either not naturalized or of limited distribution, including the first naturalized population of *Salvinia natans* in Guam (R. Miller pers. comm.). Clearly the greatest risk from potential weeds comes from aquatic species that have already arrived across the Micronesian border. Although such species could be regarded as no longer a border issue for the Region, they do represent a more immediate economic, social and ecological risk and their management is advocated (see later).

Of the 33 species scoring ≥ 80, only ten have not been recorded from Micronesia. These were (in decreasing order of risk) *Mimosa pigra, Azolla pinnata, Alternanthera philoxeroides, Salvinia molesta, Eichhornia azurea, Azolla filiculoides, Myriophyllum spicatum, Typha angustifolia, Limnocharis flava* and *T. latifolia*. The risk of entry of the *Azolla* species is seen as much more likely than the other species (each scoring 24/30 compared to scores of ≤5 for the other species).

By excluding the likelihood of entry score, a measure of weed potential and impact can be used to rank species (Table 6). Of the 12 highest ranked alien species (scores ≥ 80), six are not known to occur in Micronesia (*M. pigra, A. philoxeroides, S. molesta, E. azurea, M. spicatum, T. angustifolia* and *L. flava*).

The species in Table 7 are not known from Micronesia and all have combined scores higher than 50 (weed potential and impact score). These species are distributed via international aquarium and/or ornamental plant trades and are therefore recommended for inclusion of a 'black list' of imports to the jurisdictions of Micronesia (Table 7).

Additionally, there are a number of species that are sparingly naturalized or only known from cultivation in Micronesia and that rank higher or within the same range as the species in Table 7. These species are recommended for preventative measures prohibiting their sale and distribution (Table 8). Species listed in table 8 include the highest ranked species *E. crassipes*.

Management programs are advocated for a number of very high risk species (weed potential and impact score ≥ 70) that have very limited naturalized ranges in Micronesia (Table 9). These include some species previously regarded as indigenous, as discussed above. Additional to these species, the recently recognized naturalized population of *Salvinia natans* should also be assessed. Thorough surveys for their presence in cultivation and naturalized populations in each jurisdiction are recommended, with eradication programs advocated should their populations be rated as eradicable.

**Table 7:** High risk aquatic plant species not present in Micronesia recommended for inclusion in a 'black-list' of species prohibited from importation, with combined weed potential and impact score, and ranking out of 95 taxa assessed.

| **Species** | **Combined weed potential and impact score** | **Ranking/ 95** |
|---|---|---|
| *Myriophyllum spicatum* | 82 | 10 |
| *Typha angustifolia* | 81 | 11 |
| *Eichhornia azurea* | 80 | 12 |
| *Typha latifolia* | 78 | 13 |
| *Ludwigia peruviana* | 77 | 14 |
| *Gymnocoronis spilanthoides* | 73 | 19 |
| *Limnocharis flava* | 73 | 19 |
| *Monochoria hastata* | 73 | 19 |
| *Egeria densa* | 72 | 23 |
| *Azolla pinnata* | 69 | 24 |
| *Sagittaria sagittifolia* | 67 | 27 |
| *Najas guadalupensis* | 66 | 29 |
| *Nymphaea mexicana* | 63 | 32 |
| *Sagittaria platyphylla* | 63 | 32 |
| *Cabomba caroliniana* | 62 | 34 |
| *Najas marina* | 62 | 34 |
| *Azolla filiculoides* | 61 | 38 |
| *Sagittaria montevidensis* | 61 | 38 |
| *Heteranthera reniformis* | 60 | 42 |
| *Spirodela polyrhiza* | 59 | 43 |
| *Ludwigia adscendens* | 58 | 44 |
| *Limnobium stoloniferum* | 57 | 46 |
| *Ludwigia peploides* | 57 | 46 |
| *Neptunia oleracea* | 56 | 48 |
| *Neptunia plena* | 56 | 48 |
| *Vallisneria* spp. | 55 | 52 |

| Species | Combined weed potential and impact score | Ranking/ 95 |
|---|---|---|
| *Hydrocotyle ranunculoides* | 54 | 54 |
| *Limnobium spongia* | 54 | 54 |
| *Trapa* spp. (excluding *T. natans)* | 51 | 60 |

**Table 8:** High risk aquatic plant species present in Micronesia recommended for prohibition from sale and distribution, with combined weed potential and impact score, and ranking out of 95 taxa assessed.

| Species | Combined weed potential and impact score | Ranking/ 95 |
|---|---|---|
| *Eichhornia crassipes* | 97 | 1 |
| *Hydrilla verticillata* | 93 | 2 |
| *Pistia stratiotes* | 87 | 6 |
| *Ceratophyllum demersum* | 83 | 9 |
| *Melaleuca quinquenervia* | 77 | =14 |
| *Schinus terebinthifolius* | 77 | =14 |
| *Monochoria vaginalis* | 75 | =17 |
| *Salvinia cucullata* | 75 | =17 |
| *Myriophyllum aquaticum* | 73 | =19 |
| *Sagittaria latifolia* | 61 | =38 |
| *Salvinia natans* | 56 | =48 |
| *Nelumbo nucifera* | 55 | =52 |
| *Utricularia gibba* | 54 | =54 |
| *Nymphaea caerulea* | 53 | =57 |
| *Nymphaea lotus* | 53 | =57 |

**Table 9:** Very high risk aquatic plant species present in Micronesia recommended for evaluation for possible eradication programmes, with combined weed potential and impact score, and ranking out of 95 taxa assessed.

| Species | Combined weed potential and impact score | Ranking/ 95 |
|---|---|---|
| *Eichhornia crassipes* | 97 | 1 |
| *Pistia stratiotes* | 87 | 6 |
| *Panicum repens* | 85 | =7 |
| *Ceratophyllum demersum* | 83 | 9 |
| *Melaleuca quinquenervia* | 77 | =14 |
| *Schinus terebinthifolius* | 77 | =14 |
| *Salvinia natans* | 56 | =48 |

### 4.3 Species currently permitted for importation as aquarium plants

All the plants currently permitted as aquarium imports to Guam scored in the low range of the AWRAM, with combined weed potential and impact score < 45.

The highest ranked species (#78) was *Echinodorus cordifolius*, a native of central- and south-eastern USA, included as a quarantine weed in Western Australia (Randall 2002), but still traded in the aquarium/pond plant trade there (Champion et al., (2008). It was recently recognized in a photograph taken of a canal in Hawaii, but its status there is uncertain. It is present in cultivation in Guam, but unlikely to be a weed of much consequence.

*Cryptocoryne* species were the next highest group (#80), with *C. ciliata* and *C. spiralis*, both commonly traded species, reported as rice weeds (no indication of level of impact) in India (Moody 1989) and *C. beckettii*, *C. wendtii* and *C. undulata* naturalized in the San Marcos River, Texas and other U.S. localities (NAS 2010). These species are very popular in the aquarium trade and pose a minor risk to natural habitats, especially forest streams, in Micronesia.

*Aponogeton* species (excluding the warm temperate, water-lily like *A. distachyos*) were ranked #87. *A. crispus, A. natans, A. robinsonii* and *A. undulatus* are all reported as rice weeds (no indication of level of impact) in India and Southeast Asia (Moody 1989), with these species often occurring in seasonal pools, regrowing from tubers once these pools are flooded. Several species are included as a quarantine weed in Western Australia (Randall 2002), but they are still traded in the aquarium/pond plant trade there (Champion et al., (2008). These species are very popular in the aquarium trade and pose a minor risk to natural habitats, especially open streams and ponds and potentially savanna wetlands in Micronesia.

Other *Echinodorus* species (excluding *E. cordifolius*) are ranked #88, with Randall (2002), reporting 14 species, including *E. osiris* recorded in pond cultivation in Guam, as weeds within their native range of South America. *E. berteroi* is a native rice weed of California (Barrett & Seaman 1980; Di Tomaso & Healy 2003), but are likely to pose minor risks to Micronesia.

The remaining taxa permitted for importation occupy the bottom four rankings (ranks #92 -95). These are *Anubias* spp. (African aroids - Kasselmann 2003), *Microsorium pteropus* (a fern native to tropical Asia and New Guinea - Kasselmann 2003), *Vesicularia duyana* (a moss native to the Philippines - Kasselmann 2003, and possibly Micronesia) and the lowest ranked South American aroid *Spathiphyllum tasson* (not included as an aquatic plant by Kasselmann 2003). All are forest stream species and are unlikely to cause any impact on habitats in Micronesia.

The inclusion of these taxa on a 'white-list' for importation as aquarium plants is supported.

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# 6. References


Agami, M.; Waisel, Y. (1986). The role of mallard ducks (*Anas platyrhynchos*) in distribution and germination of seeds of the submerged hydrophyte *Najas marina* L. *Oecologia 68*: 473–475.

Agrawal, A.; Ram, H.Y.M. (1995). In vitro germination and micropropagation of water chestnut (*Trapa* sp.). *Aquatic Botany 51*: 135–146.

Andreu, J.; Vilà, M. (2010). Risk analysis of potential invasive plants in Spain. *Journal for Nature Conservation 18*: 34–44.

APHIS (2009). Action Plan for the Noxious Weeds Program. Animal and Plant Health Inspection Service Plant Protection and Quarantine (APHIS) (http://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/weed_action_plan.pdf accessed June 2010).

Barrett, S.C.; Seaman, D.E. (1980). The weed flora of Californian rice fields. *Aquatic Botany 9*: 351–376.

Bini, L.M.; Thomaz, S.M. (2005). Prediction of *Egeria najas* and *Egeria densa* occurrence in a large subtropical reservoir (Itaipu Reservoir, Brazil-Paraguay). *Aquatic Botany 83*: 227–238.

Bini, L.M.; Thomaz, S.M.; Carvalho, P. (2010). Limnological effects of *Egeria najas* Planchon (Hydrocharitaceae) in the arms of Itaipu Reservoir (Brazil, Paraguay). *Limnology 11*: 39–47.

Biosecurity Queensland (2010). Weed Fact Sheets and Pest Alerts (http://www.dpi.qld.gov.au/4790_10168.htm accessed June 2010).

Brunel, S. (2009). Pathway analysis: aquatic plants imported in 10 EPPO countries. *Organisation* Européenne et Méditerranéenne pour la Protection des Plantes/European and Mediterranean. *Plant Protection Organization Bulletin 39*: 201–213.

Carlquist, S. (1967). The biota of long-distance dispersal. V. Plant dispersal to Pacific Islands. *Bulletin of the Torrey Botanical Club 94*: 129–162.

Champion, P.D. (2005). Evaluation criteria for assessment of candidate species for inclusion in the National Pest Plant Accord. *NIWA Consultancy Report MAF05204*. 21 p.

Champion, P.D.; Burnett, D.A.; Petroeschevsky, A. (2008). Risk assessment of tradeable aquatic plant species in Australia. *NIWA Client Report AUS2008/001*, O'Connor, WA, Australia. 163 p.

Champion, P.D.; Clayton, J.S. (2000). Border control for potential aquatic weeds. Stage 1 Weed risk model. *Science for Conservation 141*. Department of Conservation, Wellington. 48 p.

Champion, P.D.; Clayton, J.S. (2001). Border control for potential aquatic weeds. Stage 2 Weed risk assessment. *Science for Conservation 185*. Department of Conservation, Wellington. 30 p.

Champion, P.D.; Clayton, J.S.; Petroeschevsky A.; Newfield, M. (in press). Using the New Zealand aquatic weed risk assessment model to manage potential weeds in the aquarium/pond plant trade. *Plant Protection Quarterly*.

Champion, P.D.; Hofstra, D.E. (2006). Organism Consequence Assessments for six pests of national concern. *NIWA Consultancy Report HAM2006-058*. 117 p.

Champion, P.D.; Hofstra, D.E.; Clayton, J.S. (2007). Border control for potential aquatic weeds. Stage 2 Weed risk management. *Science for Conservation 271*. Department of Conservation, Wellington. 41 p.

Champion, P.D.; Hofstra, D.E.; Clayton, J.S. (2010). Nipping aquatic plant invasions in the bud – weed risk assessment and the trade. *Hydrobiologia*.

Chang, C.K.; Ab Ghani, A.; Zakaria, N.A.; Yusof, M.F.; Ayub, K.R.; Lai, S.H.; Hasan, A.M.M.; Ainan, A. (2008). Rehabilitation of ex-mining pond and existing wetland for integrated stormwater management. 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK. Pp. 1–10.

Coffman, G.C.; Ambrose, R.F.; Rundel, P.W. (2010). Wildfire promotes dominance of invasive giant reed (*Arundo donax*) in riparian ecosystems. *Biological Invasions* online published 13 May 2010. 12 p.

Cook, C.D.K. (1996). Aquatic plant book. SPB Academic Publishing, Amsterdam. 228 p.

Cook, C.D.K.; Urmi-Konig, K. (1983). A revision of the genus *Limnobium* including *Hydromystria* (Hydrocharitaceae). *Aquatic Botany 17*: 1–27.

Csurhes, S. (2008). Pest plant risk assessment: kidneyleaf mudplantain *Heteranthera reniformis*. Biosecurity Queensland, Brisbane, Australia. 12 p.

Csurhes, S.; Edwards, R. (1998). Potential environmental weeds in Australia: candidate species for preventative control. Biodiversity Group, Environment Australia. Canberra, Australia. 208 p.

Daehler, C.C.; Denslow, J.S. (2010). Hawaii weed risk assessment protocol and completed weed risk assessments.

(http://www.botany.hawaii.edu/faculty/daehler/wra/description.htm accessed June 2010).

Daehler, C.C.; Denslow, J.S.; Ansari, S.; Kuo, H. (2004). A risk assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands. *Conservation Biology 18*: 360–368.

Datta, S.C.; Banerjee, A.K. (1976). The weight and number of seeds produced by rice-field weeds. *PANS 22*: 257–263.

Di Tomaso, J.M.; Healy, E.A. (2003). Aquatic and riparian weeds of the West. *University of California Publication No.3421*, Oakland CA. 442 p.

Ellison, J.C. (2009). Wetlands of the Pacific Island region. *Wetlands Ecology and Management 17*:169–206.

EPPO (2010). Invasive alien plants - European and Mediterranean Plant Protection Organization (EPPO) Lists and documentation. (http://www.eppo.org/QUARANTINE/ias_plants.htm accessed June 2010).

Esler, A.E.; Liefting, L.W.; Champion, P.D. (1993). Biological success and weediness of the noxious plants of New Zealand. Ministry of Agriculture and Fisheries report, Wellington. 218 p.

Falanruw, M.C. (2002). Terrestrial biodiversity of the Federated States of Micronesia. FSM National Biodiversity Strategy and Action Plan Project, Pohnpei. 31 p.

Finlayson, C.M. (2005). Plant ecology of Australia's tropical floodplain wetlands: a review. *Annals of Botany 96*: 541–555.

Fosberg, F.R. (1960). The Vegetation of Micronesia. 1. General descriptions, the vegetation of the Marianas Islands, and a detailed consideration of the vegetation of Guam. *Bulletin of the American Museum of Natural History Vol.119*, 76 p.

Fosberg, F.R.; Sachet, M.-H.; Oliver, R.L. (1979). A geographical checklist of the Micronesian dicotyledonae. *Micronesica 15*: 41–295.

Fosberg, F.R.; Sachet, M.-H.; Oliver, R.L. (1982). A geographical checklist of the Micronesian pteridophyta and gymnospermae. *Micronesica 18*: 23–82.

Fosberg, F.R.; Sachet, M.-H.; Oliver, R.L. (1987). A geographical checklist of the Micronesian monocotyledonae. *Micronesica 20*: 19–126.

Gordon, D.R.; Gantz, C.A.; Jerde, C.L.; Chadderton, W.L. (2010). Refining the New Zealand Aquatic Weed Risk Assessment for Florida and the U.S. Aquatic Plant Management Society, Florida.

Gordon, E.; Pacheco, S. (2007). Prey composition in the carnivorous plants *Utricularia inflata* and *U. gibba* (Lentibulariaceae) from Paria Peninsula, Venezuela. *Revista de Biología Tropical* 55: 795–803.

HEAR (2010). Plant Threats to Pacific Ecosystems. (http://www.hear.org/Pier/scientificnames/scinamec.htm accessed June 2010)

Holm, L.G.; Weldon, L.W.; Blackburn, R.D. (1969). Aquatic weeds. *Science 166*: 699–709.

Holm, L.; Doll, J.; Holm, E.; Pancho, J.; Herberger, J. (1997). World Weeds: Natural Histories and Distribution. John Wiley and Sons, New York. 1129 p.

Holm, L.; Pancho, J.; Herberger, J.; Plucknett, D. (1979). A geographical atlas of world weeds. John Wiley and Sons, New York. 391 p.

Holm, L.; Plucknett, D.; Pancho, J.; Herberger, J. (1977). The World's Worst Weeds: Distribution and Biology. University of Hawaii Press, Honolulu. 609 p.

Hosking, J.R.; Conn, B.J.; Lepschi, B.J.; Barker, C.H. (2001). Plant species first recognised as naturalised for New South Wales in 2002 and 2003, with additional comments on species recognized as naturalised in 2000–2001. *Cunninghamia 10*: 139–166.

Hussey, B.M.J.; Keighery, G.J.; Dodd, J.; Lloyd, S.G.; Cousens, R.D. (2007). Western weeds: a guide to the weeds of the Western Australia. Second Edition. Weeds Society of Western Australia, Victoria Park, WA, Australia. 294 p.

IFAS (2010). Results from the IFAS Assessment of Non-Native Plants in Florida's Natural Areas, June 2010. Institute of Food and Agricultural Sciences, University of Florida. (http://plants.ifas.ufl.edu/assessment/pdfs/results.pdf accessed June 2010).

ISSG (2010). Global Invasive Species Database, Invasive Species Specialist Group, IUCN. (http://www.issg.org/database/species/ecology.asp accessed June 2010).

Janes, R.A.; Eaton, J.W.; Hardwick, K. (1996). The effects of floating mats of *Azolla filiculoides* Lam. and *Lemna minuta* Kunth on the growth of submerged macrophytes. *Hydrobiologia 340*: 22–26.

Kadono, Y. (2004). Alien aquatic plants naturalized in Japan: history and present status. *Global Environmental Research 8*: 163–169.

Kasselmann, C. (2003). Aquarium plants. Krieger Publishing, Malabar, FL. 518 p.

Koo, S.J.; Kwon, Y.W.; Chin, D.V. (2005). Common Weeds in Vietnam. Second Edition. Saigon Plant Protection State Limited Company, Vietnam. 488 p.

Lancar, L.; Krake, K. (2002). Aquatic weeds and their management. International Commission on Irrigation and Drainage, 74 p. (http://www.icid.org/weed_report.pdf accessed June 2010).

Land and Water Australia (2010). Defeating the Weed Menace R&D Programme Publications (http://lwa.gov.au/products/list/3209 accessed June 2010).

Li, K.-Y.; Liu, Z.-W.; Guan, B.-H. (2010). Effects of nutrient levels in surface water and sediment on the growth of the floating-leaved macrophyte *Trapa maximowiczii*: implication for management of macrophytes in East Bay of Lake Taihu, China. *Limnology 11*: 95–101.

Lorence, D.H.; Flynn, T. (2009). Checklist of vascular plans in Pohnpei. *In:* Balick, M.J. (comp.) Ethnobotany of Pohnpei: plants, people and island culture. University of Hawaii press, Honolulu. Pp. 524–566.

Mackey, A.P.; Swarbrick, J.T. (1997). The biology of Australian weeds 32: *Cabomba caroliniana*. *Plant Protection Quarterly 12*: 154–165.

Marquez-Silva, G.G.; Thomaz, S.M. (2009). Biological interactions in the co-occurrence of *Eichhornia azurea* and free-floating macrophytes. *Acta Scientiarum. Biological Sciences 31*: 355–361.

Masuyama, S. (2008). Three Forms of *Ceratopteris thalictroides* in Guam. *American Fern Journal 98*: 104–115.

McFarland, D.G.; Nelson, L.S.; Grodowitz, M.J.; Smart, R.M.; Owens, C.S. (2004). *Salvinia molesta* D.S. Mitchell (Giant Salvinia) in the United States: A Review of Species Ecology and Approaches to Management. USACE, Washington, DC. 33 p.

Meyer, J-Y. (2000). Preliminary review of the invasive plants in the Pacific islands (SPREP Member Countries). *In:* Sherley, G. (ed.). Invasive species in the Pacific: A technical review and draft regional strategy. South Pacific Regional Environment Programme, Samoa. 190 p.

Middleton, B. (1999). Succession and herbivory in monsoonal wetlands. *Wetlands Ecology and Management 6*: 189–202.

Mito, T. (2006). Establishment and enforcement of the new Invasive Alien Species Act in Japan. *In:* Koike, F.; Clout, M.N.; Kawamichi, M.; De Poorter, M.; Iwatsuki, K. (eds). Assessment and Control of Biological Invasion Risks. IUCN, Gland, Switzerland. Pp. 35–44.

Moody, K. (1989). Weeds reported in rice in South and Southeast Asia. International Rice Research Institute, Manila, Philippines. 442 p.

Morita, H. (1997). Handbook of arable weeds in Japan. Kumiai Chemical Industry Co. Ltd, Tokyo. 128 p.

Motooka, P.; Castro, L.; Nelson, D.; Nagai, G.; Ching, L. (2003). Weeds of Hawaii's Pastures and Natural Areas; An Identification and Management Guide. College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa. (http://www.ctahr.hawaii.edu/invweed/weedsHi.html accessed June 2010).

NAS (2010). Nonindigenous Aquatic Species Fact Sheets, U.S. Geological Survey. (http://nas.er.usgs.gov/queries/FactSheet.aspx?Species accessed June 2010).

Nather Khan, I.S.A. (1990). Socio-economic values of aquatic plants (freshwater macrophytes) of Peninsular Malaysia. WWF Malaysia, Kuala Lumpur, Malaysia. 124 p.

Pancho, J.V.; Soerjan, M. (1978). Aquatic weeds of Southeast Asia: a systematic account of common Southeast Asian aquatic weeds. SEAMEO Regional Center for Tropical Biology (BIOTROP), Bogor, Indonesia. 130 p.

Parker, C.; Caton, B.P.; Fowler, L. (2007). Ranking nonindigenous weed species by their potential to invade the United States. *Weed Science 55*: 386–397.

Parsons, W.T.; Cuthbertson, E.G. (2001). Noxious Weeds of Australia. Second Edition. CSIRO Publishing, Victoria, Australia. 712 p.

Petroeschevsky A.; Champion, P.D. (2008). Preventing further introduction and spread of aquatic weeds through the ornamental plant trade. 16th Australian Weed Conference, Cairns. Pp. 200–302.

Pheloung, P.C.; Williams, P.A.; Halloy, S.R. (1999). A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management 57*: 239–251.

Pheloung, P.C. (2003). Contingency planning for plant pest incursions in Australia. (http://www.fao.org/docrep/008/y5968e/y5968e0u.htm accessed June 2010).

Pierini, S.A.; Thomaz, S.M. (2004). Effects of inorganic carbon source on photosynthetic rates of *Egeria najas* Planchon and *Egeria densa* Planchon (Hydrocharitaceae). *Aquatic Botany 78*: 135–146.

Pieterse, A.H.; Murphy, K.J. (eds) (1990). Aquatic weeds – the ecology and management of nuisance aquatic vegetation. Oxford University Press, Oxford. 593 p.

PROSEA (2010). Plant Resources of South–East Asia. (http://www.proseanet.org. accessed June 2010).

Randall, R.P. (2002). A global compendium of weeds. R.G & F.J. Richardson Publ., Meredith, Vic., Australia. 905 p. and (http://www.hear.org/gcw/scientificnames/ accessed June 2010).

Raulerson, L. (2006). Checklist of Plants of the Mariana Islands. *University of Guam Herbarium Contribution 37*: 1–69.

Rea, N.; Storrs, M.J. (1999). Weed invasions in wetlands of Australia's Top End: reasons and solutions. *Wetlands Ecology and Management 7*: 47–62.

Ruiz-Avila, R.J.; Klemm, V.V. (1996). Management of *Hydrocotyle ranunculoides* L.f., an aquatic invasive weed of urban waterways in Western Australia. *Hydrobiologia 340*: 187–190.

Sainty, G.; Jacobs, S. (2003). Waterplants in Australia. Sainty and Associates, Potts Point, NSW, Australia. 416 p.

Sharpe, P.R. (1986). Keys to Cyperaceae, Restionaceae and Juncaceae of Queensland. *Queensland Botany Bulletin 5*, Queensland DPI, Brisbane. 74 p.

Smith, R.J. (1983). Weeds of major economic importance in rice and yield losses due to weed competition. Pp.19–26 in Proceedings of the Conference on weed control in rice. Manila, Philippines.

South Africa Department of Environmental Affairs and Tourism (2007). Draft Alien Invasive Species List (http://www.environment.gov.za/hotissues/2007/aispecies/AIS%20Notice.pdf accessed June 2010).

Souza, W.T.Z.; Thomaz, S.M.; Murphy, K.J. (2010). Response of native *Egeria najas* Planch. and invasive *Hydrilla verticillata* (L.f.) Royle to altered hydroecological regime in a subtropical river. *Aquatic Botany 92*: 40–48.

Space, J.C.; Falanruw, M. (1999). Observations on invasive plant species in Micronesia. USDA Forest Service, Honolulu. 32 p.

Space, J.C.; Lorence, D.H.; LaRosa, A.M. (2009). Report to the Republic of Palau: 2008 update on Invasive Plant Species. U.S.D.A. Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry, Hilo, Hawaii. 227 p.

Space, J.C.; Waterhouse, B.M.; Denslow, J.S.; Nelson, D.; Mazawa, T.R. (2000). Invasive plant species on Chuuk, Federated States of Micronesia. U.S.D.A. Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry, Honolulu. 41 p.

Space, J.C.; Waterhouse, B.M.; Denslow, J.S.; Nelson, D.; Waguk, E.E. (2000). Invasive plant species on Kosrae, Federated States of Micronesia. U.S.D.A. Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry, Honolulu. 43 p.

Space, J.C.; Waterhouse, B.M.; Miles, J.E.; Tiobech, J.; Rengulbai, K. (2003). Report to the Republic of Palau on invasive plant species of environmental concern. U.S.D.A. Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry, Honolulu. 174 p.

Staples, G.W.; Herbst, D.; Imada, C.T. (2000). Survey of invasive or potentially invasive cultivated plants in Hawai‘i. *Bishop Museum Occasional Papers No. 65*. 35 p.

Stephens, K.M.; Dowling; R.M. (2002). Wetland plants of Queensland – a field guide. Csiro Publishing, Collingwood, Australia. 146 p.

Stone, B.C. (1970). The flora of Guam. *Micronesica 6*: 1–659.

Turner, C.E.; Center, T.D.; Burrows, D.W.; Buckingham, G.R. (1998). Ecology and management of *Melaleuca quinquenervia*, an invader of wetlands in Florida. *Wetlands Ecology and Management 5*: 165–178.

Tjitrosemito, S. (1993). Integrated management of paddy and aquatic weeds in Indonesia. (http://www.agnet.org/library/eb/367b/ accessed June 2010).

Udomsri, C.; Premcharoen, S.; Thawatphan, C.; Vidthayanon, C.; Vajrodaya, S. (2005). Structure of aquatic plants in Bung Khong Long, Nongkhai province, a Ramsar site of Thailand. *Kasetsart Journal (Natural Science) 39*: 64–75.

USDA (2010). Invasive and noxious weeds. United States Department of Agriculture, Natural Resources Conservation Service. (http://plants.usda.gov/java/noxiousDriver accessed June 2010).

Waterhouse, D.F. (1993). The major arthropod pests and weeds of agriculture in Southeast Asia. Australian Centre for International Agricultural Research, Canberra, Australia. 141 p.

Whistler, W.A. (1995). Wayside plants of the islands: a guide to the lowland flora of the Pacific Islands. Isle Botanica, Honolulu. 202 p.

Whitten, W.M.; Jacono, C.C. (2009). Molecular identification of invasive water-clover ferns: final report for a contract from the Florida Department of Environmental Protection. University of Florida. (http://www.flmnh.ufl.edu/herbarium/research/barcoding/dep-marsilea1-report.htm accessed June 2010).

Wisconsin DNR (2009). Invasive species: plants: literature reviews. (http://dnr.wi.gov/invasives/plants.asp accessed June 2010).

WONS (2008). Weeds of National Significance Weed Management Guide: Alligator weed (*Alternanthera philoxeroides*) (http://pandora.nla.gov.au/pan/64168/20080620-0000/www.weeds.crc.org.au/documents/wmg_alligator_weed.pdf accessed June 2010).

WONS (2008). Weeds of National Significance Weed Management Guide: Cabomba (*Cabomba caroliniana*) (http://pandora.nla.gov.au/pan/64168/20080620-0000/www.weeds.crc.org.au/documents/wmg_cabomba.pdf accessed June 2010).

WONS (2008). Weeds of National Significance Weed Management Guide: Mimosa (*Mimosa pigra*) (http://pandora.nla.gov.au/pan/64168/20080620-0000/www.weeds.crc.org.au/documents/wmg_mimosa.pdf accessed June 2010).

WONS (2008). Weeds of National Significance Weed Management Guide: Salvinia (*Salvinia molesta*) (http://pandora.nla.gov.au/pan/64168/20080620-0000/www.weeds.crc.org.au/documents/wmg_salvinia.pdf accessed June 2010).

WSSA (2008). Weed Science Society of America Weed fact sheets (http://wssa.net/Weeds/Invasive/FactSheets/index.htm accessed June 2010).

Wu, Z.; Yu, D. (2004). The effects of competition on growth and biomass allocation in *Nymphoides peltata* (Gmel.) O. Kuntze growing in microcosm. *Hydrobiologia 527*: 241–250.

Yarrow, M.; Marín, V.H.; Finlayson, M.; Tironi1, A.; Delgado, L.E.; Fischer, F. (2009). The ecology of *Egeria densa* Planchon (Liliopsida: Alismatales): A wetland ecosystem engineer? *Revista Chilena de Historia Natural 82*: 299–313.