Interim report submitted to the Hau'oli Mau Loa Foundation for the CGAPS "State Biofouling Risk Assessment Project"

Developing prudent prevention strategies for marine biofouling invasions in Hawaii

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The State of Hawaii has a unique biological heritage that has inherent cultural, ecological, and economic value. The islands' geological history and biogeographic isolation provide a rich and distinct biodiversity that is threatened by introduced and invasive species. In marine habitats, ships and boats have been the dominant source of introductions of non-native species, some of which threaten native species, ecological processes, and economic interests. Biofouling–the animals and seaweeds that attach to the submerged portions of vessels–is a major source of marine invasion in Hawaii and our project is evaluating prudent policy steps that could be taken to reduce biosecurity vulnerability to this transfer mechanism.

Sometime in the early part of the 19th century, several Indo-Pacific brittle stars, *Ophiactis savignyi*, moved from the docks and pilings of a harbor onto the shady underside of a ship's hull. Among the thick layer of seaweeds, barnacles, sponges, hydroids and other marine life, the brittle stars made themselves at home within their new habitat at the stern of the vessel. The other species provided shelter and sustenance among the nooks-and-crannies of the ship, which proved very useful for the brittle stars after the vessel disembarked the port and headed for the open ocean. After many days at sea, the vessel arrived at a sheltered bay in Hawaii and the brittle stars began a disembarkation of their own, dropping from the vessel and establishing a population in the shallow-water rocky and coral reefs. Since its introduction sometime before 1849, *Ophiactis savignyi* has persisted in large numbers today in Kaneohe Bay and Pearl Harbor[1,2,3].

The process of human-mediated species transfer to Hawaii began prior to *Ophiactis*' arrival and has endured to the present day. Along with other transfer mechanisms (vectors), such as ships' ballast water and the importation of species for aquaculture or aquaria, the distinct and rich diversity of Hawaii's marine life is being 'invaded' by species from other parts of the world. In fact, Hawaii is one of the most invaded marine regions (of comparable size) in the world. In their comprehensive evaluation of introduced and cryptogenic[4] marine species in Hawaii, James Carlton and Lu Eldredge documented 418 species.[3] This is certainly an underestimate because small, soft-bodied, and cryptic species remain to be added

Biofouling on the rudder of a ship in Micronesia, an important source region of introductions to Hawaii.

to the list over time, in addition to the new species that continue to arrive to Hawaii's shores.

For those species that have been documented, there has been a remarkable increase in the numbers of introduced and cryptogenic species recorded (Fig. 1). Since 1990, 31 cryptogenic and 66 introduced invertebrates and algae have been reported in the state.[3]

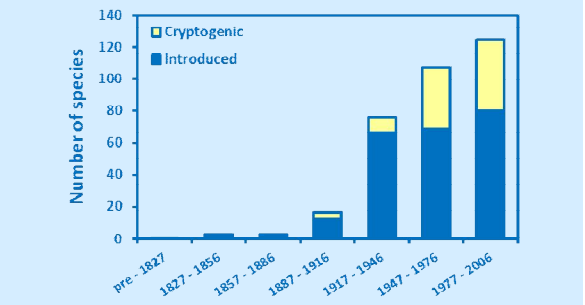

Figure 1. Records of introduced and cryptogenic marine species in Hawaii have been rising dramatically over time[5].

Invader Impacts

The establishment of introduced species in Hawaii compromises the integrity of the near-shore ecosystem. At a minimum, when introduced species become established in a new range they compete for resources and alter the dynamics of marine species communities. Some introduced species can cause major impacts to a region's ecology and economy.

Unfortunately, Hawaii has more than its fair share of problematic introduced species. Introduced by ships in 1972, the octocoral, *Carijoa riisei*, is a well-known example of a marine invader. It smothers native Hawaiian black coral and persists in the waters of Kauai, Oahu, Molokai, Maui, and Hawaii.[3,6]

Similarly, introduced seaweeds *Kappaphycus* spp. were intentionally brought to Kaneohe Bay in the 1970s for open-water commercial culturing. [3] Since their initial introduction, they have grown to dominate distinct areas of the Bay and the state is attempting to rear and release predator urchins in a control effort.[7,8] Another red seaweed, *Gracillaria salicornia*, achieves local dominance in Waikiki and removal efforts are conducted after large wave events when the seaweed washes up in large abundance on the beach.[3] The resources needed to respond to invasions can be quite substantial and require a long term commitment to mitigate persistent impacts or to cause a lasting reduction of species abundance.

Vessel biofouling: a dominant vector

Shipping and boating are crucially important economic, logistical, cultural, and recreational activities that connect Hawaii to the wider world. Similarly, the naval base at Pearl Harbor is strategically important to the state and the nation. The flux of many types of vessels to Hawaii has underpinned the state's historical and economic development and will remain an integral part of the islands' future.

However, the introduction of non-native species to Hawaii is largely occurring because of unintentional transfers of species in and on ships and boats. Species have been transferred to the state in ballast tanks of ships, in water systems of boats (bilge tanks), in the dry ballast of historical vessels, and most prominently, attached to submerged surfaces of vessels as biofouling. Up to 78% of the introduced and cryptogenic marine species in the state have been brought to the islands by vessel biofouling (Fig. 2). While other vectors have contributed significantly to the islands' invasion history–notably ballast water and the intentional importation of algae and other species for culture–no other vector ranks higher than vessel biofouling as a mechanism of marine introductions in Hawaii.

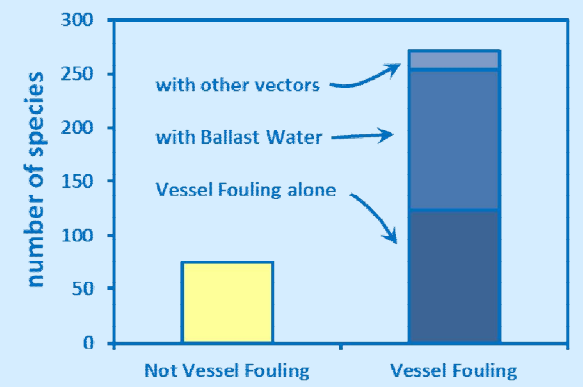

Figure 2. Out of 346 introduced marine invertebrates and algae in Hawaii[5], vector analyses suggest that up to 78% were brought to the islands via vessel biofouling.

Fortunately, vector management provides a tool to reduce and prevent introductions over time. Preventing species from becoming established is preferable to dealing with species after their arrival because vectors are more amenable to management than to post-establishment mitigation or control.

Preventing introduced species

The key to vector management is (a) understanding the vector process that causes invasions and (b) changing the process to reduce species transfers. Such efforts already exist in Hawaii for a number of invasion mechanisms, notably through state and federal management of ships' ballast water. The US Coast Guard and the Hawaii Department of Land and Natural Resources (DLNR) operate and enforce ballast water management programs that require shippers to reduce the amounts of overseas coastal ballast water being discharged in the state. A vector management policy for biofouling would play a similar role and our project is evaluating data on shipping practices to determine policy options to manage biofouling introductions.

Phase I of our project began in 2013 with a workshop on biofouling in Honolulu[9] that brought together representatives of state and federal agencies; scientists; shippers and boaters; port and harbor operators; and interested stakeholders. The workshop culminated with the development of a survey questionnaire to elucidate the current patterns (*status quo*) for vessel maintenance by Hawaii's visiting and resident shipping and boating fleets. The second phase of the project is underway and will analyze a series of data sets, including the state's invasion history, vessel traffic, and hull maintenance patterns to determine policy options for state government to consider going forward.

We are currently in the data collection phase, focused especially on vessel traffic and hull maintenance. Our data sets include: invasion history records; state and federal records of ship arrivals and ballast water discharge; questionnaire data on ship hull husbandry practices; federal and state information on dry docking and antifouling paint usage; marina records for recreational vessel traffic; boater questionnaire data; and biological information on vessel biofouling from recent and prior sampling. Our initial dataset shows that 63% of large vessels (ships) have been dry docked within the last two years, but 16% of ships had been out of dry dock for more than three years (Fig. 3). Fewer than 30% of vessels have conducted in-water cleaning since their last dry docking.

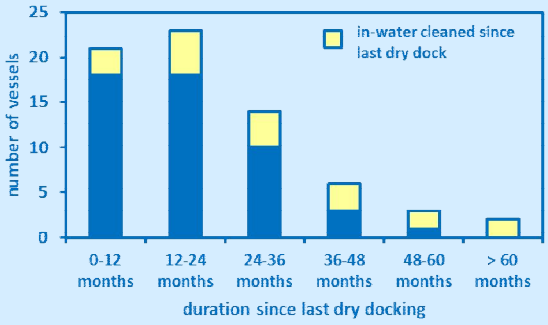

Figure 3. Dry docking and in-water cleaning patterns for ships in our initial shipper questionnaire data set (n=69).

Vector management solutions

The state and federal programs for ballast water management provide an example of successful implementation of marine vector management in Hawaii. The state's pivotal role in managing the Papahanaumokuakea Marine National Monument, including explicit provisions for preventing biofouling-mediated invasions[10], is also a globally significant vessel management program. Despite this program, the state's invasion history and recently recorded species introductions show that gaps remain in the state's biosecurity apparatus that could be incrementally resolved by implementing invasion prevention policies.

Biofouling on vessels arriving to the main Hawaiian Islands is the prominent vector management gap that requires attention. Prudent steps that raise awareness of the biofouling vector and promote frequent management of vessels' submerged surfaces will strive to reduce the invasion rate in Hawaii and to conserve the unique and diverse biotic heritage of the islands.

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References & Notes:

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2. Coles SL, DeFelice RC, Eldredge LG, Carlton JT (1999). Historical and recent introductions of nonindigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands. Marine Biology. 135: 147–158.
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4. Cryptogenic means 'of unknown origin' and refers to species for whom more research is needed to determine biogeographic ranges
5. Figure 1 and 2 uses data for 346 introduced and cryptogenic marine invertebrates and algae from Carlton & Eldredge (2009), thereby excluding the fish, plants and insects covered in that monograph.
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9. Hawaii Alien Aquatic Organism Task Force (AAOTF) Biofouling Workshop. February 4th & 5th, 2013; Hawaii Kai, Honolulu, Hawaii.
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