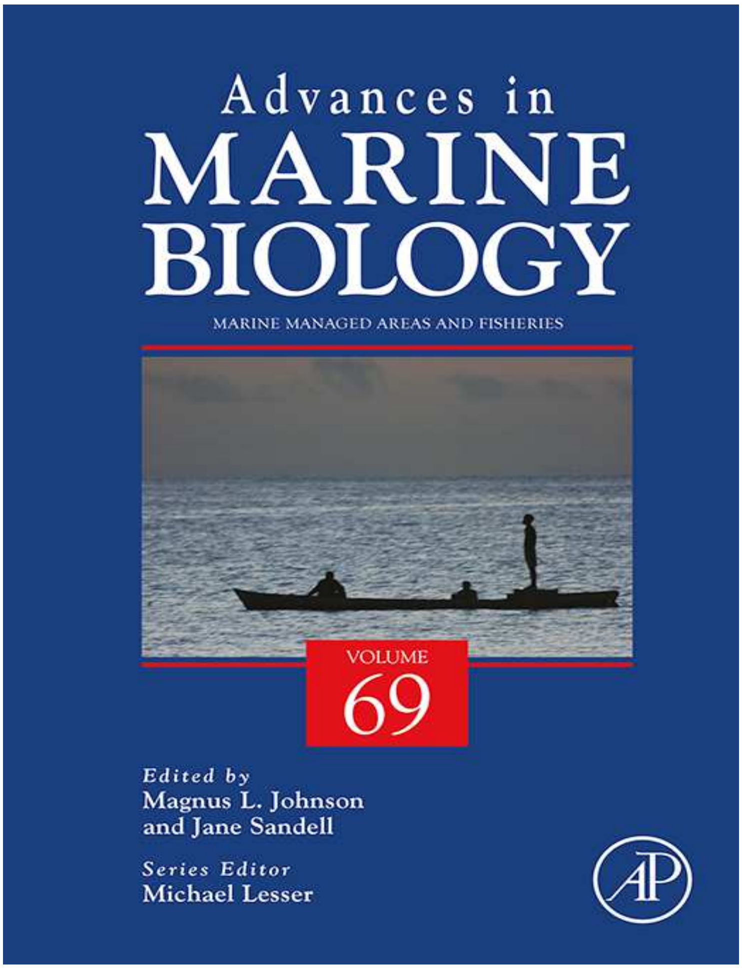

From Alan M. Friedlander, Kostantinos A. Stamoulis, John N. Kittinger, Jeffrey C. Drazen and Brian N. Tissot, Understanding the Scale of Marine Protection in Hawai'i: From Community-Based Management to the Remote Northwestern Hawaiian Islands. In: Magnus L. Johnson and Jane Sandell, editors, *Advances in Marine Biology, Vol. 69*, Oxford: Academic Press, 2014, pp. 153-203.
ISBN: 978-0-12-800214-8

CHAPTER FIVE

Understanding the Scale of Marine Protection in Hawai'i: From Community-Based Management to the Remote Northwestern Hawaiian Islands

Alan M. Friedlander*,†, Kostantinos A. Stamoulis*, John N. Kittinger‡, Jeffrey C. Drazen§, Brian N. Tissot¶

*Fisheries Ecology Research Laboratory, Department of Biology, University of Hawaii, Honolulu, HI, USA
†National Geographic Society, Washington, DC, USA
‡Conservation International, Betty and Gordon Moore Center for Science and Oceans, Honolulu, HI, USA
§Department of Oceanography, University of Hawaii, Honolulu, HI, USA
¶Marine Laboratory, Humboldt State University, Trinidad, CA, USA

Contents

Advances in Marine Biology, Volume 69
ISSN 0065-2881
http://dx.doi.org/10.1016/B978-0-12-800214-8.00005-0

Abstract

Ancient Hawaiians developed a sophisticated natural resource management system that included various forms of spatial management. Today there exists in Hawai'i a variety of spatial marine management strategies along a range of scales, with varying degrees of effectiveness. State-managed no-take areas make up less than 0.4% of nearshore waters, resulting in limited ecological and social benefits. There is increasing interest among communities and coastal stakeholders in integrating aspects of customary Hawaiian knowledge into contemporary co-management. A network of no-take reserves for aquarium fish on Hawai'i Island is a stakeholder-driven, adaptive management strategy that has been successful in achieving ecological objectives and economic benefits. A network of large-scale no-take areas for deepwater (100–400 m) bottomfishes suffered from a lack of adequate data during their initiation; however, better technology, more ecological data, and stakeholder input have resulted in improvements and the ecological benefits are becoming clear. Finally, the Papahānaumokuākea Marine National Monument (PMNM) is currently the single largest conservation area in the United States, and one of the largest in the world. It is considered an unqualified success and is managed under a new model of collaborative governance. These case studies allow an examination of the effects of scale on spatial marine management in Hawai'i and beyond that illustrate the advantages and shortcomings of different management strategies. Ultimately a marine spatial planning framework should be applied that incorporates existing marine managed areas to create a holistic, regional, multi-use zoning plan engaging stakeholders at all levels in order to maximize resilience of ecosystems and communities.

Keywords: Hawai'i, MPAs, Scale, Community-based management, Aquarium fishery, Marine spatial planning, Overfishing, Governance

ABBREVIATIONS

BRFA bottomfish restricted fishing area
CBSFA community-based subsistence fishing area
DAR Division of Aquatic Resources
DLNR Department of Land and Natural Resources
FMA Fisheries Management Area
FRA fish replenishment area
KIR Kaho'olawe Island Reserve
MHI Main Hawaiian Islands
MLCD marine life conservation district
MMA marine managed area
MPA marine protected area
MSP marine spatial planning
NOAA National Oceanic and Atmospheric Administration
NWHI Northwestern Hawaiian Islands
PMNM Papahānaumokuākea Marine National Monument
USFWS United States Fish and Wildlife Service
WHFC West Hawai'i Fishery Council
WPRFMC West Pacific Regional Fisheries Management Council

1. INTRODUCTION

1.1. Bio-physical description

The Hawaiian Archipelago consists of two regions: the populated main Hawaiian Islands (MHI), and the mostly uninhabited atolls, islands, and banks of the Northwestern Hawaiian Islands (NWHI). The archipelago extends from the island of Hawai'i (19°N) northwest to Kure Atoll (28°N), a distance of over 2500 km (Figure 5.1). This vast expanse is connected by geological origin and geographic isolation, and is subject to large spatial gradients in oceanography, erosion, and geomorphology (Grigg, 1997; Juvik et al., 1998). The MHI consist of eight high volcanic islands that range in age from active lava flows on the east side of Hawai'i Island to 7 million-year-old Kaua'i (Juvik et al., 1998). Beginning at Nihoa and Mokumanamana (Necker Island) (about 7 and 10 million years old, respectively) and extending to Midway and Kure atolls (both about 28 million years old), the NWHI represents the older portion of the emergent Hawaiian Archipelago (Grigg, 1997; Grigg et al., 2008).

The Hawaiian Archipelago resides in the middle of the North Pacific Subtropical Gyre and is exposed to large open ocean swells and strong trade winds that have a major impact on the structure of the nearshore marine ecosystems, with distinctive communities being sculpted by these dynamic natural processes (Dollar, 1982; Gove et al., 2013; Grigg, 1983). At the northern end of the chain, Kure is the world's highest latitude atoll and is located at the "Darwin Point" where coral accretion is balanced by losses due to bioerosion, mechanical erosion, and subsidence (Grigg, 1982, 1997). Circulation is primarily from east to west and intensifies to the south, however, in the lee of the islands, surface currents driven by wind combine with large-scale ocean currents to yield more complicated flow patterns such as eddies (Flament et al., 1996; Lobel and Robinson, 1986).

The Hawaiian Archipelago occupies its own province in the tropical Indo-West Pacific region (Briggs and Bowen, 2012). The geographic isolation of Hawai'i has resulted in some of the highest endemism of any tropical marine ecosystem on the Earth (Jokiel, 1987; Kay and Palumbi, 1987; Randall, 1998). Some of these endemics are dominant components of the nearshore marine community, resulting in a unique ecosystem that has extremely high biodiversity and conservation value (DeMartini and Friedlander, 2004; Maragos et al., 2004).

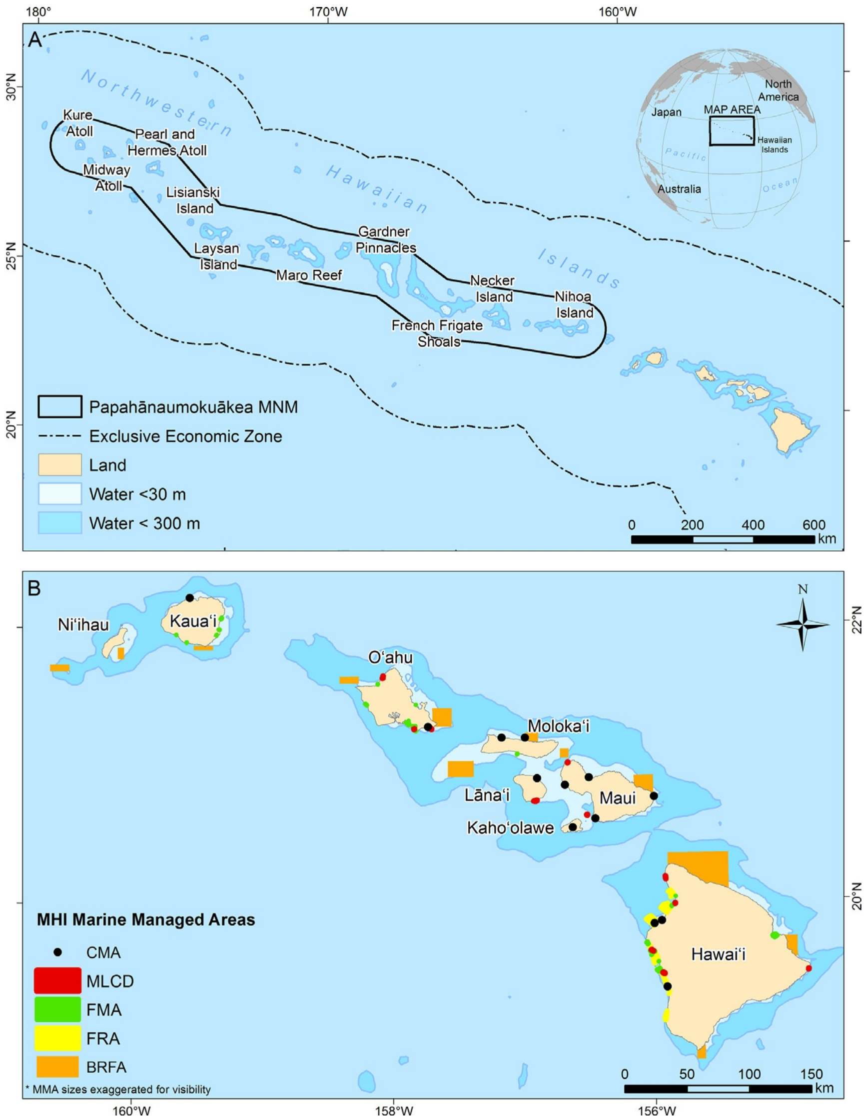

Figure 5.1 Map of (A) Hawaiian Archipelago showing Papahānaumokuākea Marine National Monument (PMNM), (B) Main Hawaiian Islands (MHI) showing locations of marine managed areas. These include community-based co-management areas (CMA), state marine life conservation districts (MLCDs), state Fisheries Management Areas (FMA), Fish Replenishment Area network (FRA), and the bottomfish restricted fishing areas (BRFA).

Hawai'i provides habitat for a wide variety of species protected by federal acts and state statutes. Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world, with approximately 14 million birds representing 21 species (Friedlander et al., 2008; Harrison, 1990). The Hawaiian monk seal (*Monachus schauinslandi*) is the only endangered pinniped occurring entirely within US waters, with a current population estimated at only 1200 seals—a decrease of about 60% since the 1950s (Antonelis et al., 2006). The Hawaiian green turtle stock comprises a single closed genetic stock that is endemic to the Hawaiian Archipelago (Bowen et al., 1992). Stock size in the 1970 were estimated to be at 20% of pre-exploitation biomass but protection since that time has resulted in population levels >80% of pre-exploitation levels with a 5% intrinsic growth rate (Chaloupka and Balazs, 2007).

1.2. Historical use and management of marine resources

Hawaiians of old (pre-western contact, <AD 1778) developed sophisticated and complex management systems for marine resource use (Friedlander et al., 2013; 'Ī'ī, 1993; Kahā'ulelio, 2006; Kamakau, 1976; Malo, 1951). These societies depended on fishing and gathering for survival, which motivated them to acquire a sophisticated understanding of the factors that caused limitations and fluctuations in their marine resources. In traditional Hawaiian society, the basic unit of land division and socioeconomic organization was the ahupua'a, which generally encompassed a watershed catchment unit that included interior uplands through valleys into the sea and was managed adaptively according to resource availability, life cycles, and fluctuations (Kaneshiro et al., 2005; Kirch, 1989). Ahupua'a units were nested within districts (moku) that were hierarchical and roughly corresponded to biophysical attributes of island ecosystems (e.g. windward/leeward and wet/dry districts of islands; Malo, 1951).

At the local (ahupua'a) and district (moku) levels, fishing activities were strictly regulated by a system of rules that were embedded in socio-political structures and religious systems (the kapu system) (Malo, 1951; Poepoe et al., 2007). While the basic unit of land management was the ahupua'a, the basic unit of marine resource management and harvesting was the moku, or district (McGregor, 2007). Under this management regime, Hawaiian communities were able to maintain a high level of productivity and fisheries yield over several centuries prior to Western contact (McClenachan and Kittinger, 2013).

Following Western contact, a variety of socio-political factors led to the demise of the traditional system of resource management in the late eighteenth to early nineteenth centuries (Friedlander et al., 2013; Ralston, 1984; Seaton, 1974). The annexation by the United States and the Organic Act of 1900 that followed resulted in the erosion of traditional fishing rights, which ultimately created open-access to coastal fisheries for residents and non-residents alike (Kosaki, 1954; Tanaka, 2008). The early 1900s also saw the centralization of economic activities and fisheries markets in Honolulu and large increases in the commercial landing of marine resources (Bell and Higgens, 1939; Cobb, 1901).

Just prior to World War II, commercial fishing in Hawai'i was a multimillion dollar industry that employed hundreds directly and thousands indirectly. Subsistence and commercial fishing pressure increased due to the post-war growth in population, increases in boat ownership, introduction of export-driven fisheries (e.g. aquarium trade, tuna), and other technological advances, such as refrigeration, which still continue today (Kittinger, 2010; Schug, 2001). Following statehood, Hawai'i saw a rapid growth in tourism, an increasingly urban resident population, and the continued development of shoreline areas for tourism and recreation, which resulted in changes in the character of the coastal fisheries as they became dominated by recreational anglers and a greater number of part-time commercial fishers who curtailed their fishing to take advantage of more lucrative economic activities (Friedlander, 2004; Shomura, 2004).

1.3. Contemporary use and management of marine resources

In 2012, Hawai'i's fishing industry generated US $91.5 million from 13.3 million kg of fish, ranking it twelfth in value among US states (National Marine Fisheries Service, 2014). Residents of Hawai'i have the highest per capita seafood consumption in the United States with an annual total of >17.6 million kg (Geslani et al., 2012). The longline fishery for pelagic species, primarily bigeye tuna (*Thunnus obesus*) and swordfish (*Xiphias gladius*), accounts for the vast majority of the catch by value (National Marine Fisheries Service, 2014). Longline fishing is prohibited within 80–120 km from shore, depending on the location and time of year. Although pelagic fisheries are by far the most important economically, Hawai'i's non-pelagic fisheries have substantial cultural, subsistence, commercial, and recreational value (Lowe, 2004; Pooley, 1993).

Much of Hawai'i's marine habitat is deep (>100 m) in contrast to continental regions elsewhere that have broad shelves. These deeper waters show high consistency in hydrographic conditions since they are below the permanent thermocline. Dramatic changes in biological communities are observed with depth but relatively few changes occur horizontally (Chave and Mundy, 1995; Yeh and Drazen, 2009). In the 1960s, aggregations of pelagic armorhead (*Pentaceros richardsoni*) were found at the Hancock Seamounts to the NW of Kure Atoll and heavily exploited at depths up to 500 m (Uchida and Tagami, 1984). This fishery collapsed by the early 1980s and briefly switched to alfonsinos, *Beryx decadactylus* (to about 1000 m), and pink coral for the jewellery trade (Clark and Koslow, 2008). Other seamounts nearby were also exploited until bottom trawling within the Hawaiian Archipelago was banned in 2004 (Hawai'i Administrative Rules, 2004). Throughout the archipelago, a hook-and-line fishery for deep water snappers and groupers has existed for decades from depths of 100–400 m (Haight et al., 1993), and is the second-most valuable commercial fishery in Hawai'i. In addition to the commercial catch, the non-commercial catch for this fishery from 1950 to 2005 was estimated to be over two times higher than reported commercial landings (Hospital and Beavers, 2012; Zeller et al., 2008).

Nearshore fisheries constitute a mix of commercial, recreational, and subsistence sectors that land a diverse catch. The Hawai'i marine aquarium fishery is one of the state's most lucrative nearshore fisheries with an annual reported value of over $2 million (Walsh et al., 2013). Although the true economic value of this fishery was estimated to be two to five times higher than reported values in the past (Cesar and van Beukering, 2004; Walsh et al., 2003), recent analysis indicate under-reporting by collectors is not significant (Walsh et al., 2013). The major coastal commercial fishery in Hawai'i by weight is the net fishery for bigeye scad (akule, *Selar crumenopthalmus*), along with mackerel scad (opelu, *Decapterus* spp.). This fishery accounts for nearly 80% of the entire coastal catch, with commercial fishers reporting nearly 388,000 kg of akule and opelu landed in 2010.

It is difficult to separate nearshore fisheries into sectors, as fishers can engage in multiple activities—both commercial and non-commercial—in a single trip (Glazier, 2007). Non-commercial fishing includes subsistence/consumptive, recreational, and cultural fishing and gathering activities that occur in open ocean and nearshore coastal zones. Non-commercial fishing is the most prevalent type of extractive activity on most coral reefs in Hawai'i (Geslani et al., 2012; Kittinger, 2013). However, the catch is largely unreported or undocumented and can substantially exceed reported commercial landings (Hospital et al., 2011; Zeller et al., 2008).

Furthermore, recreational and subsistence fishers take more species using a wider range of fishing gear (Friedlander and Parrish, 1997).

Hawai'i's nearshore marine environment provides numerous ecosystem services and is vital to the state's approximately $800 million per year marine tourism industry (Friedlander et al., 2008). The economic value of Hawai'i's coral reefs was estimated at $10 billion with direct economic benefits of $360 million per year in 2002 (Cesar and van Beukering, 2004). Hawai'i's nearshore resources also have cultural importance for the Native Hawaiian community. The continuance of subsistence fishing activities and associated socio-cultural practices are critical to the transfer of Native Hawaiian culture to subsequent generations (Kikiloi and Graves, 2010; McGregor et al., 1998, 2003).

Despite their economic and cultural significance, reefs near urbanized areas have declined due to a variety of human-mediated pressures. Reef fish populations and their associated fisheries have declined dramatically around Hawai'i due to intensive fishing pressure, land-based pollution, destruction of habitat, invasive species, and other threats. These are driven by a growing human population, export-driven markets for resources, access to technological innovations (e.g. motorized boats and freezers for storing catch), and introduction of new and overly efficient fishing techniques (e.g. inexpensive monofilament gill nets, SCUBA, GPS) (Friedlander, 2004; Friedlander et al., 2003, 2013; Shomura, 1987; Smith, 1993; Williams et al., 2008). Furthermore, there is poor compliance with state fishing laws and regulations and insufficient enforcement, which is partially attributed to lack of resources, capacity, and political will (Tanaka et al., 2012; Tissot et al., 2009).

1.4. Marine protected areas in Hawai'i

Today, myriad state and federal authorities provide for the management of Hawai'i's coastal resources (Lowry et al., 1990) that primarily rely on top-down governance approaches implemented by government resource agencies and managers (Kittinger, 2013). The State of Hawai'i has numerous marine protected areas (MPAs) and other marine managed areas (MMAs)—natural area reserves, fisheries management areas, marine life conservation districts (MLCDs), various protective subzones, military defensive areas, and National Park coastlines (Figure 5.1B). Hawai'i established its first MPAs over 45 years ago. Since that time, many MPAs and MMAs have been created with varying levels of protection ranging from complete 'no-take' areas to areas that allow a wide variety of activities to

Table 5.1 Percent of total area by island restricted to fishing in the main Hawaiian Islands nearshore marine (0–18 m) waters by gear type

Location	No/negligible fishing/access	Some fishing permitted	Laynet	Spear	Pole and line	Throw-net	AQ fishing
MHI total	**4.8**	**95.2**	**72.5**	**94.9**	**94.7**	**94.4**	**92.0**
Hawai'i	0.2	99.8	85.5	98.9	96.7	96.5	81.9
Kaho'olawe	100.0	–	–	–	–	–	–
Kaua'i	5.9	94.1	93.9	94.1	94.1	94.0	93.9
Lāna'i	–	100.0	96.5	96.5	100.0	96.5	96.5
Maui	1.7	99.3	–	98.3	98.3	98.3	98.3
Moloka'i	–	100.0	99.9	100.0	100.0	100.0	99.9
Molokini	100.0	–	–	–	–	–	–
Ni'ihau	–	100.0	100.0	100.0	100.0	100.0	100.0
O'ahu	6.3	93.7	67.0	93.3	93.7	93.3	93.0

AQ, aquarium fish fishery.

occur within their boundaries (Table 5.1). Designation of many of these areas was not based on comprehensive biological selection criteria or a systematic ecological assessment. Rather, the existing system was built piecemeal and is reflective of various needs to manage user conflicts, safeguard protected species, or on the wishes of local communities (Friedlander et al., 2007a,b). Below, we present five case studies detailing different spatial scales of marine management in Hawai'i, which are organized starting from local scale (state-managed MMAs: <1 km^2) to archipelagic scale (Marine National Monument: $>100{,}000$ km^2). This comparison enables a detailed examination of the effect of scale on various aspects of marine protection in Hawai'i with potential applications across the globe.

2. MPA CASE STUDIES

2.1. Marine managed areas

2.1.1 Establishment

Within the MHI, there are at least 33 state-managed areas that limit fishing activities in nearshore marine waters, with an average area of 1.0 (0.01–6.2) km^2 and a total area of 33.8 km^2 (Figure 5.2A). Hanauma Bay Nature Reserve was established in 1967 and is likely the most visited MPA

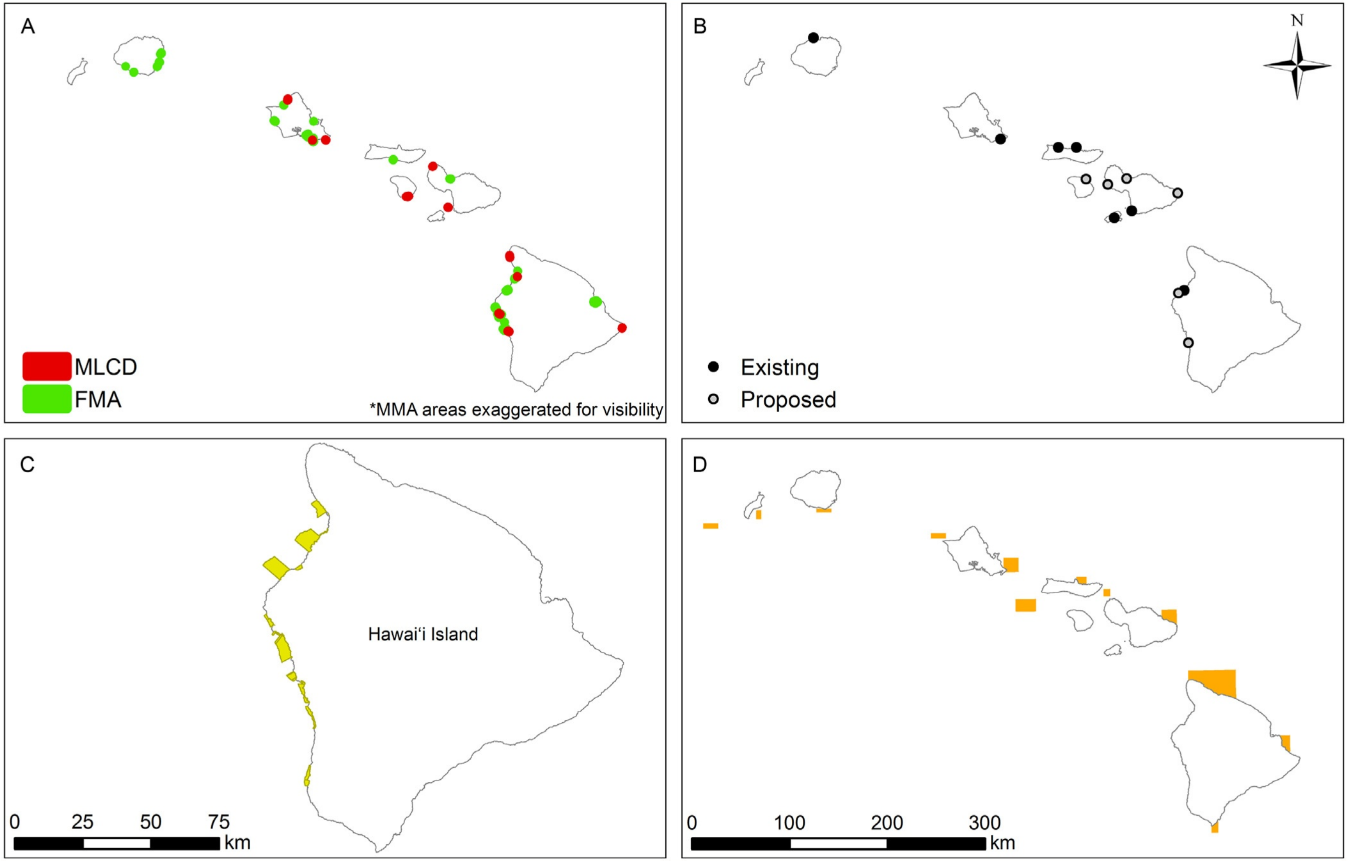

Figure 5.2 (A) State managed marine areas in the main Hawaiian Islands including marine life conservation districts (MLCDs) and Fisheries Management Areas (FMAs), (B) locations of community managed/co-management areas, (C) West Hawai'i Aquarium Fish MPA network (FRAs), and (D) bottomfish restricted fishing areas (BFRAs).

in the world with more than 1 million annual visitors in a 0.4-km^2 area. In addition to 11 MLCDs (areas designed to conserve and replenish marine life) and 22 Fisheries Management Areas (FMAs—areas designed to resolve conflicts among users, including fishers), members of the public have limited or no-access to the shoreline and nearshore waters within and around military or security areas on O'ahu and Kaua'i (Pearl Harbor, Kaneohe Bay Marine Corps Base Hawai'i, Barking Sands Pacific Missile Range Facility, and Honolulu Reef Runway) or in Hawai'i Volcanoes National Park on Hawai'i Island.

MLCDs are established by the state's Department of Land and Natural Resources (DLNR), as authorized by statute. Suggestions for areas to be included in the MLCD system may come from the State Legislature or general public. In addition, the DLNR 's Division of Aquatic Resources (DAR) regularly conducts surveys of marine ecosystems throughout the state, and may recommend MLCD status for areas that appear particularly promising. Criteria for designating MLCDs include: (1) the marine life and its potential for increase, (2) its "pristine state", (3) compatibility with existing uses within and adjoining the MLCD, (4) geological features that provide well-defined boundaries for enforcement, and (5) the site's ability to support public safety and accessibility from the shoreline (DAR, 1992).

The large number of restricted-access or restricted-fishing areas in the MHI gives the impression of a substantial network of actively managed and protected marine areas, but in reality the majority of these areas are small, and nearly all allow some or several forms of fishing within their boundaries. MLCDs are the most restrictive of protected area designations in the State of Hawaii, but some types of fishing are permitted within 6 of the 11 existing MLCDs. The proportion of nearshore MHI waters in no-take and negligible-take areas including fully protected MLCDs, extremely limited access reserves, and no-access zones is only 4.8% (Table 5.1). The large majority of this is in military and security no-access zones around O'ahu and Kaua'i, or in the Kaho'olawe Island Reserve (KIR). Therefore, the extent of complete no-take areas on other islands is extremely limited, with only 0.4% of nearshore MHI waters less than 18 m depth (an approximation of inshore habitats that are the primary targets for fishing of reef and reef-associated species) are within no-take MPAs. Nearly, 70% of nearshore waters are not spatially managed for fishing or specially restricted in any way (Table 5.2).

2.1.2 Ecological performance

A comprehensive examination of existing MLCDs showed that areas fully protected from fishing had higher fish biomass, larger overall fish size,

Table 5.2 Marine managed and restricted-access areas containing nearshore (0–18 m) marine waters in the main Hawaiian Islands

Location	Area (km^2)	No-take MMA	State regulated areas-partial closure MMA	Lay gill-net prohibited area	Little/ no-access	Restricted access	No spatial management
MHI total	**1074.8**	**0.4**	**5.3**	**22.9**	**2.7**	**2.1**	**68.7**
Hawai'i	174.7	0.2	19.0	8.1	–	3.1	72.9
Kaho'olawe	18.1	–	100.0	–	–	–	0.0
Kaua'i	166.6	–	0.4	–	5.9	3.8	90.0
Lāna'i	32.2	–	3.5	–	–	–	96.5
Maui	133.6	1.7	–	100.0	–	–	0.0
Moloka'i	141.7	–	0.1	–	–	–	99.9
Molokini	0.3	100.0	–	–	–	–	100.0
Ni'ihau	83.3	–	–	–	–	–	100.0
O'ahu	324.7	0.5	1.2	30.4	5.9	3.2	63.3

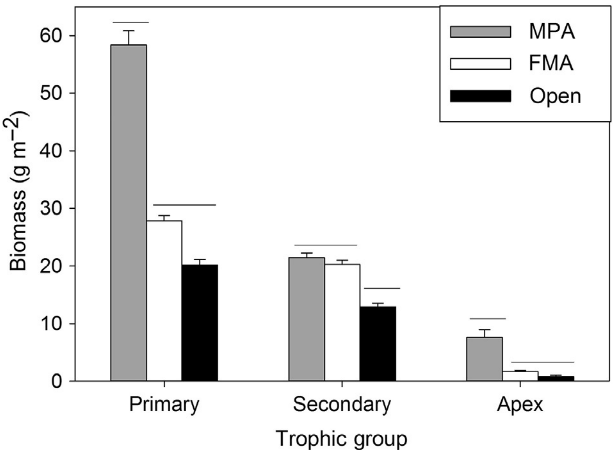

Figure 5.3 Comparisons of fish biomass by trophic group among marine managed areas and areas open to fishing in Hawai'i. MLCDs, marine life conservation districts; FMA, Fisheries Management Areas. (Overall ANOVA—$F_{2,2255}=10.42$, $P<0.05$). Primary, primary consumer; Secondary, secondary consumer; Apex, apex predator. Horizontal lines above bars show management types that are not significantly different for each trophic group at $\alpha=0.05$ (Tukey's HSD tests). *Adapted from Friedlander et al. (2007a).*

and higher biodiversity than adjacent areas of similar habitat quality (Friedlander et al., 2007a,b). Overall fish biomass was 2.6 times greater in the MLCDs compared to open areas. In addition, apex predators and other trophic groups were more abundant and larger in the MLCDs (Figure 5.3), illustrating the effectiveness of these closures in conserving fish populations within their boundaries. The differences in biomass among management types for all three trophic groups reflects the fact that in Hawai'i, overfishing occurs at all trophic levels with targeted species occurring across all trophic group. Habitat type, protected area size, and level of protection from fishing were all important determinates of MLCD effectiveness with respect to their associated fish assemblages (Friedlander et al., 2007a,b). Overall, MLCDs protected from fishing that had high habitat complexity and good habitat quality (e.g. high coral cover and low macroalgae cover) had higher values for most fish assemblage characteristics. Areas that only provided partial protection from fishing due to rotating closures or other means were no more effective than areas completely open to fishing (Williams et al., 2006).

MPAs can supplement adjacent fisheries through increased production and export of pelagic eggs and larvae, and net emigration of adults and juveniles, otherwise known as spillover (Gaines et al., 2010; McClanahan and Mangi, 2000; Russ, 2002). Stamoulis and Friedlander (2013) measured adult spillover of fish species from Pūpūkea-Waimea MLCD on the north shore of Oʻahu and found a significant negative gradient of resource fish biomass across the protected area boundary extending nearly 1 km into the fished area.

MLCDs in Hawaiʻi were established to support the state's conservation and education objectives, not to enhance fish stocks. As a consequence, most of the MLCDs are currently too small to provide noticeable fisheries benefits (Friedlander et al., 2007a). Their small size and limited habitat types do not allow for the entire fish assemblage to function in a natural manner compared to large and relatively pristine areas such as the NWHI. Closing areas to fishing is far from a new idea in the management of marine resources. Pacific Islanders traditionally used a variety of closures that were often imposed to ensure large catches for special events or as a cache for when resources on the usual fishing grounds ran low (Johannes, 1978, 1981; Jupiter et al., 2012; Ruddle, 1996). Rotational closures have been less successful in contemporary Hawaiʻi where there are few or no controls on effort once the area is open to fishing. The Waikīkī -Diamond Head FMA rotational closure has been an ecological failure with fish biomass tending to increase slightly during the 1- to 2-year closure periods, but the scale of these increases is insufficient to compensate for declines during open periods (Williams et al., 2006). The net effect was that, between 1978 and 2002, total biomass declined by around two-thirds. Coincident with this decline was the virtual disappearance of larger fishes (>40 cm) of fishery-target groups. This management action has created a 'derby' mentality where fishing effort is greatly intensified in a rush to fish once these areas are re-opened.

2.1.3 Socio-economic performance

Marine ecosystems generate a wide range of goods and services that benefit Hawaiian society, including supporting important livelihood and food provisioning functions, as well as cultural practices, customs, and traditions. Declining reef health threatens the societal benefits that these ecosystems provide (Bell et al., 2011; Sadovy, 2005). Currently, less than 1% of the state's budget is directed towards natural resource management, despite a high reliance on ecosystem health to support the state economy's dependency on tourism. Hanauma Bay MLCD, for example, receives more than 1 million visitors and generates more than $35 million annually. The net benefits (including direct and indirect expenditures and future willingness to pay) greatly exceeds the net-costs to society (Figure 5.4; Cesar and van Beukering, 2004).

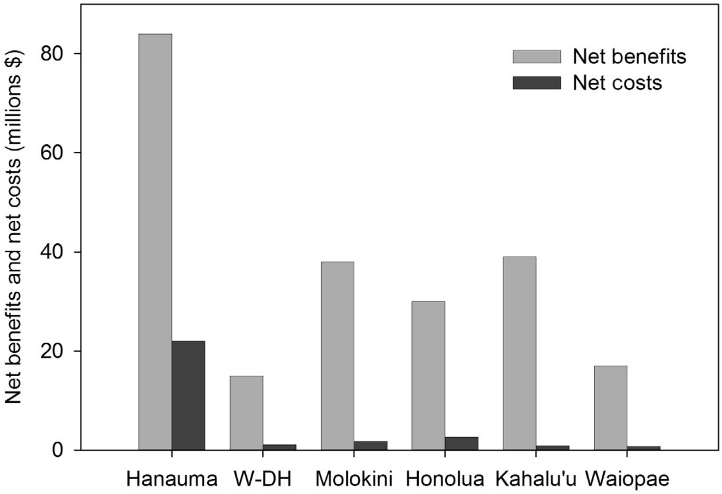

Figure 5.4 Net benefits and costs for six marine managed areas (MMAs) in Hawai'i. W-DH, Waikīkī Diamond Head Fisheries Management Area (FMA). Cost estimates combine the investment costs and recurrent costs associated with expenditures in services, education/awareness, monitoring/assessment, enforcement/compliance, and other costs such as infrastructure. Overall benefits were estimated by aggregating recreational, fishery, and educational benefit values. *Adapted from van Beukering and Cesar (2004).*

The economic value of six MMAs in Hawai'i ranges from $6 million for the Waikīkī -Diamond Head Fisheries Management Area to $650 million for Hanauma Bay MLCD (van Beukering and Cesar, 2004). A cost-benefit analysis of management options among MMAs found that the economic benefit–cost ratio was very high ($\overline{X} = 18.8 \pm 13.0$, range: 3.8–40.5; van Beukering and Cesar, 2004). This means that assuming people pay their stated willingness-to-pay value on entry to the MMA, over time the benefits outweigh the costs by a factor of 40, although the absolute values should be treated with caution.

Data from nearly 1000 users at Pūpūkea MLCD showed that most users had protectionist (i.e. biocentric, nature-centered) value orientations towards reefs (Needham et al., 2008). Overall satisfaction was extremely high and despite moderate-to-high crowding at some sites, most users encountered fewer people than their maximum tolerance. A similar study at Molokini MLCD with over 1000 users surveyed found that almost all had biocentric values towards the environment in general and protectionist-specific values towards coral reefs (Szuster and Needham, 2010). Results showed that overall satisfaction of visitors to Molokini MLCD was extremely high, although a large proportion were dissatisfied with the inability to escape crowds and that they did not learn about the history of the area or Hawaiian culture.

2.1.4 Overview and future prospects

There is strong opposition to the creation of additional MPAs in Hawai'i by the large and vocal fishing community. Fishing is a large part of the local culture and fishers often view MPAs as having a direct negative impact on their activities—this is often exacerbated by prevailing opinions that land-based pollution comprises a larger threat to nearshore marine ecosystems than overexploitation (e.g. for Maunalua Bay, Kittinger, 2013). While most marine reserves in Hawai'i are either too small or poorly placed to generate significant fishery benefits, spillover of juvenile and adult fishes from protected areas can be a very tangible benefit of MPAs that may serve to improve perception of this type of management among fishers (Russ and Alcala, 1996). Williams et al. (2009) and Stamoulis and Friedlander (2013) provide examples of adult fish spillover from MPAs in Hawai'i. This information should be made accessible to the fishing public along with education about the less tangible, though greater fisheries benefits, provided by larval export from MPAs (Palumbi, 2004; Sladek Nowlis and Friedlander, 2005). The negative perception of MPAs in Hawai'i is perhaps the greatest obstacle to the use of this valuable management tool. This issue can be addressed through public relations efforts and a re-branding of MPAs to something more palatable to fishers. In addition, managers need to engage the fishing community in an equitable stakeholder participatory approach, which includes alternatives such as technical measures, evaluated on a case-by-case basis.

To realize the full fishery benefits of MPAs in Hawai'i, substantial increases in size and number of protected areas will need to occur. To support higher fish biomass and greater numbers and diversity of species, future protected area in the MHI should include a mosaic of habitats with a range of complexities and depths to accommodate the wide range of species found in Hawaiian waters (Friedlander et al., 2007a). In addition, consideration should be given to the habitat requirements and life histories of the species being protected, the level of fishing and other pressures on the resources in adjacent areas, and the degree of enforcement (Foley et al., 2013).

The State of Hawai'i should systematically create a statewide network of MMAs encompassing existing MMAs that utilizes an ecosystem-based approach and direct community stewardship. Public participation from the beginning of the process and long-term community co-management with DLNR is essential for success. The State Legislature must exhibit the vision to move forward expeditiously and provide a welcoming venue for all stakeholders committed to healthy ocean ecosystems (Antolini et al., 2003).

2.2. Community-based management

2.2.1 Establishment

In Hawai'i, there is increased interest among communities and coastal stakeholders in integrating aspects of Native Hawaiian knowledge systems and customary practices into contemporary management (Kittinger et al., 2012). Communities have increasingly explored the development of co-management partnerships between state resource management agencies and community groups to incorporate aspects of traditional ecological knowledge and customary marine tenure and to devolve some management authority to local scales where it was traditionally based (Friedlander et al., 2013). Communities can enter into a co-management relationship with the State of Hawai'i either through the legislative process (e.g. as a stand-alone legislative act) or by working directly with DLNR through its administrative rule-making process to establish a community-based subsistence fishing area (CBSFA), for the purposes of reaffirming and protecting fishing practices customarily and traditionally exercised for purposes of Native Hawaiian subsistence, culture, and religion (Kittinger et al., 2012). The state of Hawai'i passed legislation for the designation of CBSFAs in 1994 with the intent of revitalizing local fisheries through customary Hawaiian practices and tenure. The CBSFA legislation was specifically directed towards Native Hawaiian communities "for the purpose of reaffirming and protecting fishing practices customarily and traditionally exercised for purposes of Native Hawaiian subsistence" (Hawaii Revised Statutes, HRS, 2005: Chapter 188–22.6).

Co-management can take many forms but generally involves shared management authority and responsibility between resource users or community groups at the local level and governmental agencies (Berkes, 2010). For the purpose of this analysis, we considered two categories of co-management areas: existing co-management areas which have been designated as CBSFAs though are awaiting approval of their management plans (Hā'ena, Kaua'i and Mo'omomi, Moloka'i) or areas where state or federal management co-exists with community stewardship (e.g. Kalaupapa, Moloka'i; Kaho'olawe; 'Ahihi-Kina'u, Maui) and co-management areas which are proposed through the CBSFA legislature or other MMA mechanisms (e.g. Wailuku & Hana, Maui; Maunalei, Lāna'i; Ka'ūpūlehu, Hawai'i) (Figure 5.2B). We used a standard depth range of 0–18 m bounded by watershed boundaries or those specified in management plans to map co-management areas. The existing co-management areas have an average area of 10.7 km^2 and a total area of 74.5 km^2, and the proposed areas make up another 29.2 km^2.

The island of Kaho'olawe is a special case; it was a *de facto* marine reserve during the US Military bombing era, and since 1990, it has been under the administration of the state's Kaho'olawe Island Reserve Commission (KIRC), with only limited take of marine life permitted for cultural, spiritual, and subsistence purposes in an 18-km^2 area, making it the largest area protected from most fishing in the MHI (Friedlander et al., 2013). For the purpose of this comparison, we considered Kaho'olawe as an existing co-management area. Ni'ihau is the smallest inhabited island in Hawai'i and is privately owned with a resident population of about 130 Native Hawaiians. Ni'ihau has no stores, and inhabitants fish and farm for subsistence (Tava and Keale, 1990). Although no formal rules have yet to be established on Ni'ihau, the community has developed general guidelines for permitted fishing activities through local peer pressure, and those visiting from outside are encouraged to follow these guidelines (Friedlander et al., 2013). Because of the lack of a formal management plan, we did not include Ni'ihau in our estimate of total existing co-management areas though it would double the estimate of community managed areas with a nearshore area of 83.3 km^2.

2.2.2 Ecological performance

Scientific surveys of various locations around Hawai'i show that locations under community-based management with customary stewardship harbour fish biomass equal to or greater than that found in many MPAs in Hawai'i and substantially greater than areas open to fishing (Friedlander et al., 2002, 2003, 2013). These results are consistent with findings by McClanahan et al. (2006) when comparing MPAs and collaborative management areas in Indonesia and Papua New Guinea. Owing to the lack of formal rules associated with many of these community managed areas, enforcement is typically through informal means including self-regulation and via local peer pressure and site-based monitoring of activities and resource condition. A number of these locations are in remote areas with limited access, thus allowing the community greater control over these resources and also potentially reducing overall fishing pressure.

2.2.3 Socio-economic performance

Despite interest from more than 19 communities, in the nearly 20 years since the act allowing designation of CBFSAs was passed, only two communities have successfully designated CBSFAs, and none currently have an approved management plan (Higuchi, 2008; Kittinger et al., 2012; Levine and Richmond, 2014). Nonetheless, community interest in co-management remains quite high (Ayers and Kittinger, 2014). This interest derives from several sources—first, by transferring some authority to the local level, co-management is more aligned with traditional forms of government, which endowed local resource managers with the authority to develop and implement place-based management efforts (Higuchi, 2008; Kittinger et al., 2012; Poepoe et al., 2007). In this way, co-management is viewed by many community members as more legitimate than top-down forms of governance. Second, local management can be more responsive to community needs. For example, one of the basic functions of nearshore fisheries in Hawai'i and elsewhere in the Pacific is to provide a source of seafood (Vaughan and Vitousek, 2013). As with MPAs, co-management areas can be highly managed, but unlike MPAs, they provide opportunities for harvest, providing food provisioning and cultural services to communities. A burgeoning literature documents these important functions (e.g. Cinner and Aswani, 2007; Kittinger, 2013; Vaughan and Vitousek, 2013), and community-based management can be tailored to meet community goals for fisheries. In addition, co-management areas lend themselves well to adaptive management because their rate of change is limited only by the capacity of the co-managers to accept it.

Co-management planning can also carry significant social costs. As the co-management planning process is arduous, it requires significant resources from communities, the state, and bridging organizations such as non-governmental organizations. Further, the process can be stymied by a variety of factors, including lack of human, financial, and organizational capacity to successfully engage in the planning and implementation process. In Hawai'i, there are two instances—Mo'omomi and Hā'ena—where communities self-organized, built consensus around a management plan, and collectively acted to achieve a modicum of decision-making over resource rules in their area (Friedlander et al., 2013; Poepoe et al., 2007). Despite the presence of enabling legislation, and in some cases extraordinary community effort and collective action, co-management in Hawai'i has been hindered by a lack of capacity in communities and at the state management agency, institutional culture and rigidity at the partner resource management agency, and an ambiguous, complicated administrative rule-making process (Ayers and Kittinger, 2014).

2.2.4 Overview and future prospects

Unfortunately, implementation of the CBSFA legislation has not lived up to expectations due to many challenges and has so far failed to be fully implemented in any community (Levine and Richmond, 2014; Ayers and Kittinger, 2014), although interest in developing local-state partnerships and devolving authority to community levels still remains very high among coastal stakeholders. Despite numerous obstacles to formal governmental authorization, a number of communities are currently strengthening local influence and accountability for local marine resources through revitalization of local traditions and resource knowledge (Friedlander et al., 2013).

The return to the local scale of management represents a form of contemporary adaptation of traditional management practices to modern governance contexts (Poepoe et al., 2007). There are several important challenges that hinder effective implementation of co-management legislation and policy. These include developing a standard operating procedure for the State of Hawai'i to engage fruitfully with communities, developing a viable model of practise to build community capacity to plan for and engage in co-management, and resourcing these efforts through a diverse set of partnerships and funding mechanisms (Ayers and Kittinger, 2014; Gutiérrez et al., 2011; Levine and Richmond, 2014; Ostrom et al., 2007).

Despite these challenges, a variety of community-based initiatives have emerged to ensure multigenerational knowledge-sharing and to build capacity across the state to protect and perpetuate traditional knowledge. Non-profit organizations, state and federal agencies, and communities are working in concert towards these ends, and communities are taking advantage of a great number and variety of legal and policy mechanisms to partner with the State of Hawai'i in collaborative management initiatives. These recent actions provide promise for future co-management of fisheries in Hawai'i.

2.3. West Hawai'i aquarium fish MPA network

2.3.1 Establishment

In 1999, an MPA network was implemented to protect against declines of reef fish harvested for the live aquarium trade around the island of Hawai'i (Tissot and Hallacher, 2003; Figure 5.2C). This network was implemented on the west coast of Hawai'i Island (hereafter West Hawai'i) to reduce conflict between aquarium fishers and other marine resource users (e.g. dive operators, recreational divers) as well as encourage sustainable marine resource management (Capitini et al., 2004; Tissot, 2005). The network, contained within the West Hawai'i Regional Fishery Management Area, comprised nine fish replenishment areas (FRAs), where take of any reef fishes for the aquarium trade was illegal, and when combined with existing MPAs, these FRAs closed 35.2% of the total coastline to aquarium fishing (Tissot et al., 2009). The FRAs have an average area of 17.1 (1.8–40.1) km^2 and combined area of 153.9 km^2.

The MPA network was established by recommendations from a community-based team of stakeholders, the West Hawai'i Fishery Council (WHFC), and the Hawai'i DAR. The WHFC through a collaborative dispute resolution process proposed the location of the FRAs in West Hawai'i (Capitini et al., 2004). Because one goal of West Hawai'i's MPA network was to reduce user conflict between aquarium fishers and other groups, primarily dive charter operators and the tourism industry (Stevenson and Tissot, 2013), the placement of the MPAs was based on both conflict "hotspots" and expert testimony (Capitini et al., 2004). This approach resulted in establishing many of the MPAs within West Hawai'i's west catch zone, where high human population densities, tourist infrastructure, and major ports exist.

2.3.2 Ecological performance

The creation of a network of no-take areas for aquarium fishes in West Hawai'i in 1999 has increased the abundance of targeted aquarium species, while at the same time increasing the value of the fishery (Tissot et al., 2004a, 2009; Figure 5.5). Overall, the top 20 species of aquarium fishes increased 24% between pre-(1999–2000) and post-MPA implementation (2010–2012). The two top targeted species, yellow tang (*Zebrasoma flavescens*) and goldring surgeonfish (*Ctenochaetus strigosus*), which together account for 92% of the total aquarium catch in the state showed significant increases over time (88% and 37%, respectively), as did three other important aquarium fish species (Walsh et al, 2013). Tissot et al. (2004b) found that habitat quality, FRA size (especially reef width), and density of adult fishes were associated with significant recovery of fish stocks. Of particular importance are areas of high finger coral (*Porites compressa*) cover, which is critical habitat for juvenile yellow tang and young-of-year of other important fishery species (Walsh, 1987). In addition, variation in the abundance and distribution of both

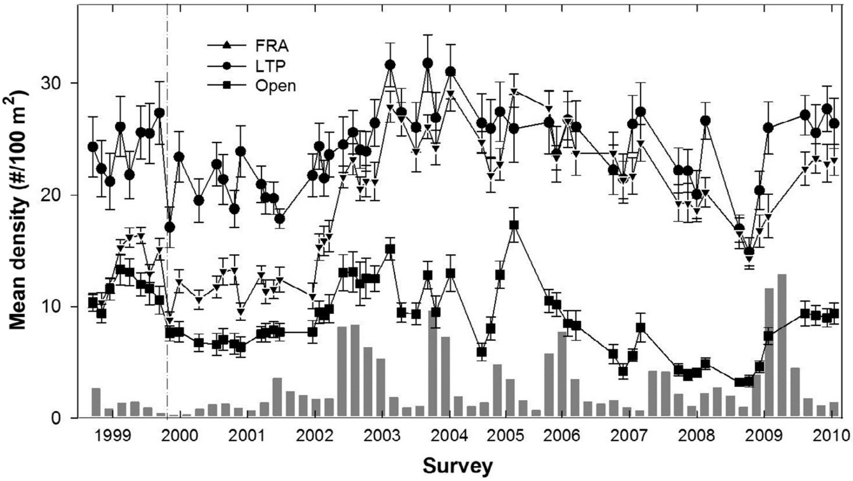

Figure 5.5 Changes in the abundance of yellow tang over time in West Hawai'i, 1999–2010 in three study area categories. FRA, fish replenishment areas established in 1999, LTP, long-term protected sites (closed ≥10 year prior to 1999), and Open areas, areas open to aquarium collecting. Histograms are the abundance of YOY (Young-of-the year) (William Walsh and Brian Tissot, unpublished data).

juvenile and adult habitats, and geomorphology of the reef, may influence effectiveness of these FRAs (Ortiz and Tissot, 2008, 2012).

Research has demonstrated both adult spillover and larval seeding of yellow tangs in the FRA network. Surveys of adult fishes within-relative to outside-MPAs show that densities at MPA boundaries in areas open to fishing are significantly higher than fished areas at distance from boundary areas (Williams et al., 2009). Moreover, genetic analyses (parentage based on microsatellite DNA) has demonstrated both general northward within-island larval dispersal and seeding via larval connectivity among local populations of yellow tang (Christie et al., 2010). Such studies of population connectivity are crucial for understanding how MPA networks function at the metapopulation level and how to design effective MPA networks at both island- and archipelago-level scale (Grorud-Colvert et al., 2014).

2.3.3 Socioeconomic performance

Analysis of catch reports and fisher interviews indicate that the West Hawaii FRA network significantly displaced fishing effort from the central to the northern and southern coastal regions of the island farther from easy access ports (Stevenson et al., 2013). Estimated catch revenues and experimental catch per unit effort were statistically greater as distance from port increased.

Both perceived fishing cost and travel time increased significantly post-MPA network implementation. Although the MPA network displaced fishing effort, fisher socioeconomic well-being was not compromised; likely by expanding their operating range, as well as favourable market factors that helped offset potential economic losses. Although there is evidence of adult yellow tang spillover and larval dispersal from within West Hawai'i's MPA network (Christie et al., 2010; Williams et al., 2009), the gradual decline in their abundance in waters remaining open to fishing (Figure 5.5) suggests that fishing mortality is likely greater than the rates of replenishment provided by the network. Fishers indicated their economic status was unchanged or marginally improved since the MPA network was implemented (Stevenson et al., 2013). Therefore, although the MPA network had a negative impact on distance travelled and cost, these attributes were perhaps offset by exogenous factors (e.g. price increase for fishes), such that the net change for economic status was constant or marginally positive, and thus may have stabilized other socio-economic well-being attributes.

Therefore, in addition to changes in fishing tactics that occurred post-MPA network (Stevenson et al., 2011), fishers were able to either maintain or potentially increase their fishing yield because the waters where they re-allocated effort to were either underexploited or more biologically productive than the pre-MPA fishing sites. It is possible that the redistribution of fishing effort synergistically acted with favourable market forces to influence fisher socio-economic well-being post-MPA network; however, the long-term viability of the fishery and the management strategy are yet to be determined.

The effectiveness of the FRA network has also been associated with an increase in the productivity of the aquarium fishery. Since 2000, the total catch and value of this fishery have increased by 39% and 59%, respectively. Approximately 79% of the fish caught in the state and 68% of the total aquarium catch value presently comes from Hawai'i Island (Walsh et al., 2013). There has also been an increase in permit holders, in the number of active fishers, and improvements in fishing effectiveness that could also account for some or all of these changes (Stevenson et al., 2011).

2.3.4 Overview and future prospects

The FRAs are considered a successful case of the MPA network implementation and a marine conservation success due in part to the unique nature of the aquarium fish fishery in West Hawai'i and the fact that the FRAs prohibit only one type of fishing, rather than attempting to prohibit all take, and the therefore excluding the broader fishing community (Rossiter and Levine, 2014). Moreover, the key targeted fish, yellow tang, reproduce quickly and have relatively small home ranges (Claisse et al., 2009), allowing for rapid recovery after collection. In addition, aquarium fish fishers are a small and somewhat marginalized group, the fishery is not considered a cultural right that needs to be protected, and revenues and livelihoods are restricted to a small number of fishers. These factors help simplify enforcement and compliance with FRA regulations. Clear scientific guidelines, careful planning and design, and extensive long-term involvement of local stakeholders in co-management with the state government have all contributed to the success of the FRAs (Rossiter and Levine, 2014). Social conflicts, however, have continued, necessitating the state's adoption of additional technical measures for West Hawai'i, including prohibited species lists and restrictions on scuba-spearfishing (Dawson, 2014). Ongoing adaptive management is an additional hallmark of effective and sustainable management and one that bodes well for the future of the West Hawai'i's FRAs.

A decade after the FRAs were established, surveys indicate that these MPAs were moderately effective in reducing conflict; however, encounters between stakeholders continued to occur and dive operators perceived aquarium fish fishing as a serious threat to the coral reef ecosystem (Stevenson and Tissot, 2013). Moreover, polarized value orientations towards the aquarium fish trade confirmed pervasive social values conflict indicating that MPAs were inadequate for resolving long-term conflict between groups who hold highly dissimilar value orientations towards the use of marine resources. Future marine spatial planning (MSP) and MPA siting processes should include stakeholder value and conflict assessments to avoid and manage tensions between competing user groups (Stevenson and Tissot, 2013).

2.4. Bottomfish restricted fishing areas

2.4.1 Establishment

In 1998, following a steady decline in catch rates and evidence that the two most commercially valuable species in the bottomfish fishery (ehu—*Etelis carbunculus* and onaga—*Etelis coruscans*) may be overfished, the State of Hawai'i DLNR implemented 19 bottomfish restricted fishing areas (BRFA) throughout the MHI. The Magnuson-Stevens Act imposed a mandate on the Western Pacific Regional Fisheries Management Council (WPRFMC) to restore the stocks of species listed as overfished to healthy levels within a 10-year time period. Since most of the MHI bottomfishing grounds are within state rather than federal waters, WPRFMC turned to DAR to address this problem. The BRFAs were spread throughout the MHI and were designed to protect 20% of the designated 0–400 m essential fish habitat for onaga and ehu (Parke, 2007). The closure of these areas took effect on June 1, 1998 and their effectiveness, in terms of the quantity and type of habitat protected and their effect on commercial landings, was subsequently reviewed in 2005 (Moffitt et al., 2006). Only 5% of preferred habitat (e.g. hard bottom high relief, structurally complex substrates) was believed to occur within the boundaries of the BRFAs, and DAR's commercial catch data analysis furthermore indicated that modifications to the BRFA system were warranted. In 2007, as a result of ongoing overfishing, additional restrictions were imposed, including a 6-month seasonal closure, reduced non-commercial bag limits, mandatory permits, vessel markings, and a revision of the BRFAs that reduced the number of restricted areas to 12 but increased the area protected to include more essential bottomfish habitat based on comprehensive multi-beam sonar habitat mapping since the original 1998 closures (Figure 5.2D; Parke, 2007; Moore et al., 2013; Sackett et al., 2014). The average area of the BRFAs is 172.6 (40.8–907.3) km^2, with a total area of 2071.9 km^2. Because the BRFAs were designed as boxes for ease of navigation, they extend into deeper waters and only 710 km^2 occur at depths between 100 and 400 m where bottomfish are found (Parke, 2007).

2.4.2 Ecological performance

A monitoring programme has been in place for a subset of the BRFAs since 2007. Due to the great depths of this fishery, monitoring is accomplished using autonomous stereo baited camera systems (Merritt et al., 2011). Two of the BRFA's boundaries remained unchanged since 1998. While no differences were detected in species relative abundance between these two zones and neighbouring fished areas, evaluation of size-frequency distributions found that two commercially valuable species (onaga and opakapaka—*E. coruscans* and *Pristipomoides filamentosus*) were significantly larger inside the BRFA at Ni'ihau, the most remote of the MHI (Moore et al., 2013). No positive effects of protection were observed for the second monitored BRFA located off Hawai'i Island, which when established in 1998 did not include sufficient area of preferred habitat and is also close to the second largest port in the state.

The deep bottomfish populations inside KIR (18 km^2) were compared to neighbouring fished areas, and results suggested positive local effects of protection, with diversity of commercially harvested species higher inside the reserve (Drazen et al., 2010). Protection at KIR may have eliminated or reduced selective harvest and therefore increased diversity. Furthermore, the average sizes of many commercially harvested species were larger in KIR and possessed greater proportions of sexually mature fishes compared to fished areas, although onaga, a highly sought after species, were smaller inside KIR.

The most compelling evidence for the ecological effects of the BRFAs comes from comparing time series of the BRFA populations to neighbouring fished areas. A 4-year time series in three BRFAs showed that size increased significantly inside the BRFA for several species but declined or remained unchanged where fishing occurred (Figure 5.6; Sackett et al., 2014). The species showing these trends were also the most economically important of the deep bottomfish (e.g. onaga, opakapaka, ehu). One species, *P. sieboldii* (kalekale), showed a reverse pattern (Figure 5.6A and E). Kalekale are generally not targeted by commercial fishers because of their small body size (Kelley et al., 2006) and declines in length may result from competition with, or predation by, larger target species (Lizaso et al., 2000). Relative abundance showed fewer significant patterns over time with increases for onaga and opakapaka inside two BRFAs while there were little or no changes outside these BRFAs over time.

Differences among the BRFAs were also evident and likely influenced by the duration of protection from fishing. For example, the oldest BRFA (Ni‘ihau, protected approximately 14 years) showed more mature fishes inside compared to outside the reserve for each species examined, and species richness in adjacent fished habitats increased while remaining unchanged inside the reserve, possibly due to spillover (Sackett et al., 2014). BRFAs with an intermediate duration of protection (Penguin Bank and Makapu‘u) had positive protection effects (i.e. increases in mean fish lengths and relative abundance, Figure 5.6B and F), and the youngest BRFA (Pailolo Channel, protected approximately 4 years, Figure 5.6G) showed little change over the duration of protection. These results are consistent with other studies that suggest that at least 15 years of protection are necessary to see reliable benefits of protection (Molloy et al., 2009; Russ and Alcala, 2010). Nonetheless, the predominant finding of more abundant, larger, and more mature fishes inside the BRFAs compared to outside these zones could suggest that the BRFAs have benefited Hawai‘i’s deepwater fish populations.

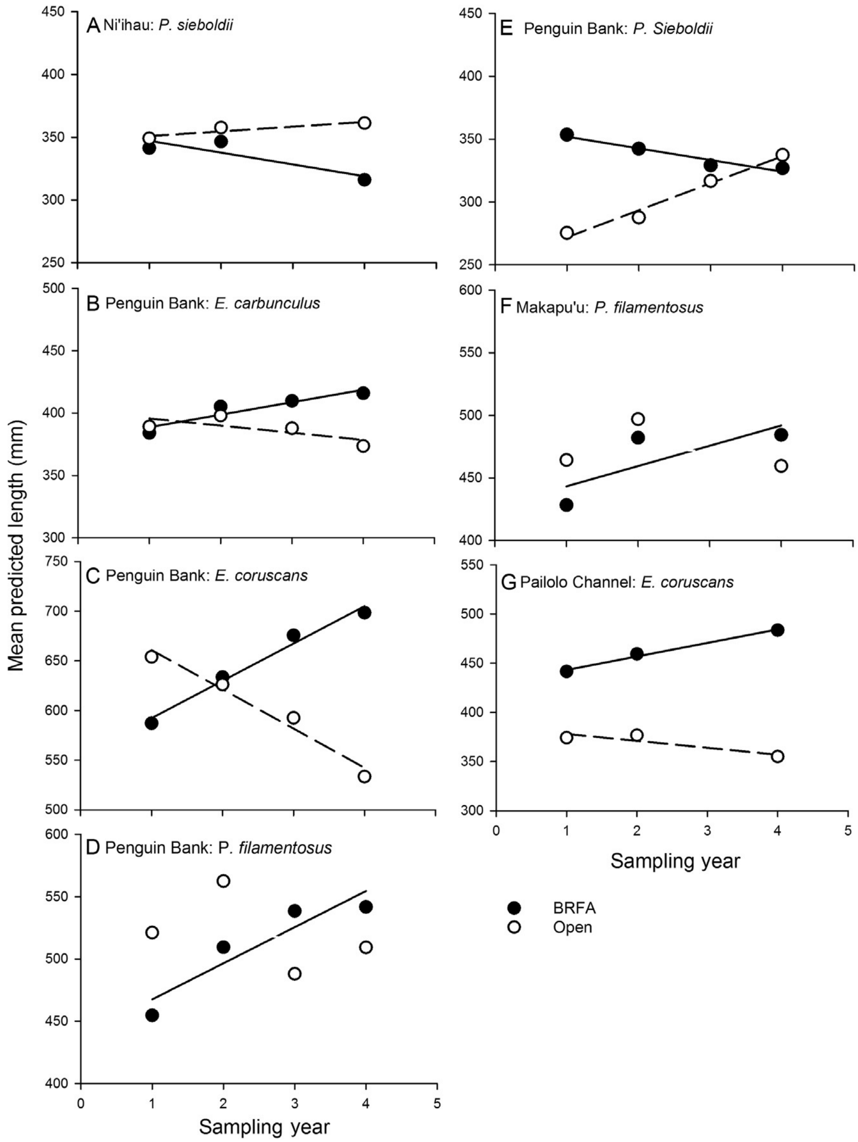

Figure 5.6 Changes in mean predicted fish length over time inside and outside bottomfish restricted fishing areas (BRFAs). Solid lines show significant trends inside BFRAs, and dashed lines show significant trends outside BFRAs ($P < 0.05$). The genera displayed are *Etelis* and *Pristipomoides*. *Adapted from Sackett et al. (2014).*

2.4.3 Socio-economic performance

The bottomfish fishery in the MHI is composed of a complex mix of commercial, recreational, cultural, and subsistence fishermen. Fifty-one per cent of fisherman surveyed in 2010 were 55 years old or more and had targeted bottomfish for an average of 19 years (Hospital and Beavers, 2012). Participants were more likely to identify themselves as Asian or Native Hawaiian/ Pacific Islander relative to the general population of the state of Hawai'i (Hospital and Beavers, 2012). While fishery highliners appear to be able to regularly cover trip expenditures and turn a profit, many supplement their income with other fishing activities. Based on average catch disposition of MHI bottomfish, it is clear that for a large majority of fishery participants, the social and cultural motivations far outweigh the economic benefits (Hospital and Beavers, 2012).

Mail surveys on attitudes and perceptions from 519 bottomfish fishermen found that some fishermen were concerned over a lack of scientific evidence that BRFAs enhance bottomfish populations and how large the BRFAs should be (Hospital and Beavers, 2012). Respondents also questioned why there are both total allowable catch (TAC) management and BFRAs and expressed frustration about a lack of enforcement of the BFRAs. The study highlighted the need for a more thorough evaluation of the protected areas, as well as the need for reliable estimates of recreational catch. Zeller et al. (2008) estimated non-commercial catches were twice as high as reported commercial catches by using adjustment ratios applied to commercial time-series data. Independent estimates of recreational bottomfish catch and effort are needed to better address uncertainty in these key management parameters.

2.4.4 Overview and future prospects

Though the local effects of the BRFAs on commercially harvested species are clear, because of the longevity of these species (e.g. >40 years for opakapaka, Andrews et al., 2012), it is likely that benefits to the fishery in terms of enhanced larval export and adult spillover will take even more time to accrue. Longevity increases, growth rates declines, and other productivity parameters changes with depth, likely increase the time required to observe obvious benefits of MPAs to regional deep water fisheries (Drazen and Haedrich, 2012).

The majority of the commercial fishing industry dislikes or even actively opposes the BRFA system (Hospital and Beavers, 2014). However, despite a lack of active enforcement, positive local effects on commercially harvested species are still observed. Opposition to the BRFAs has been bolstered by NMFS adopting a TAC management scheme in 2006, just prior to the revision of the BRFA boundaries (Hospital and Beavers, 2014). The TAC is based on a stock assessment that principally uses fishery-dependant catch data. In 2010, the quota was increased substantially and it was determined that the stock was no longer in a state of overfishing. The WPRFMC recommended that the BRFAs be eliminated but because they are under the purview of the state no action was taken at that time. This year (2014) under continuing pressure from fishers and WPRFMC, the state may open 6 of the 12 BRFAs to fishing.

2.5. Papahānaumokuākea Marine National Monument

2.5.1 Establishment

Protection of the NWHI began in 1909 with the creation of the Hawaiian Islands National Wildlife Refuge for the purpose of safeguarding nesting seabird colonies from overexploitation (Executive Order 1019). In 2000, President Clinton created the NWHI Coral Reef Ecosystem Reserve and in 2001 initiated the process to designate a National Marine Sanctuary (Executive Orders 13178 and 13196). The state of Hawai'i also recognized the significance of the NWHI in establishing the NWHI State Marine Refuge (Kittinger et al., 2010). In 2006, President Bush established the NWHI Marine National Monument under the authority of the Antiquities Act of 1906 (16 U.S.C. 431). Subsequently renamed the Papahānaumokuākea Marine National Monument (PMNM), it is the single largest conservation area under the US flag, and one of the largest marine conservation areas in the world, encompassing 362,073 km^2 (Figure 5.1B; Toonen et al., 2013).

PMNM includes a number of pre-existing federal conservation areas: the NWHI Coral Reef Ecosystem Reserve, managed by the Department of Commerce through the National Oceanic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries; Midway Atoll National Wildlife Refuge, Hawaiian Islands National Wildlife Refuge, and Battle of Midway National Memorial, managed by the Department of the Interior through the United States Fish and Wildlife Service (USFWS). These areas remain in place within the Monument, subject to their applicable laws and regulations in addition to the provisions of the Proclamation (Kittinger et al., 2011). The NWHI also includes state of Hawai'i lands and waters, managed by the DLNR as the NWHI Marine Refuge and the State Seabird Sanctuary at Kure Atoll. These areas also remain in place and are subject to their applicable laws and regulations. The governance arrangement for the monument represents a new model in US MPA management, requiring two federal agencies and the State of Hawai'i to collaboratively manage the NWHI (Kittinger et al., 2011).

In 2010, the Monument was inscribed as a UNESCO World Heritage Site for both natural and cultural value. Pursuant to the proclamation, full protections took effect in 2011 with the closure of the last remaining fishery (bottomfish fishery). In January 2010, however, the National Marine Fisheries Service signed an agreement with the remaining bottomfish fishers to surrender their federal fishing permits in exchange for compensation; as a result, all commercial fishing ended in January 2010. Although some fishing effort was re-directed towards the MHI, a number of vessels dropped out of the fishery all together. Extraction is now limited to subsistence take by visiting scientists, residents of Midway Atoll and Native Hawaiian cultural practitioners, as well as minimal extraction for research purposes. Due to the limited number of permitted entries and negligible extraction for research, the monument is primarily considered a no-take reserve.

2.5.2 Ecological performance

The remoteness and protective status of the NWHI have resulted in a relatively undisturbed state compared with the MHI and many other marine-based ecosystems in the world (Friedlander and DeMartini, 2002; Friedlander et al., 2008; Pandolfi et al., 2005; Williams et al., 2008). Because of its remoteness and limited fishing, the NWHI is one of the few places left in the world that is sufficiently pristine to study how unaltered ecosystems are structured, how such ecosystems function, and how they can be most effectively preserved. One of the most striking and unique components of the NWHI ecosystem is the abundance and dominance of large apex predators such as sharks and jacks (Friedlander and DeMartini, 2002), which exert a strong top-down control on the ecosystem (DeMartini and Friedlander, 2006; DeMartini et al., 2005) and have been depleted in most other locations around the world (Myers and Worm, 2003, 2005).

A comparison between NWHI and MHI revealed dramatic differences in the shallow reef fish assemblages with standing stock in the NWHI nearly threefold greater than in the MHI with over 54% of the total fish biomass in the NWHI consisting of apex predators, whereas this trophic group accounted for less than 3% of fish biomass in the MHI (Friedlander and DeMartini, 2002). Recent archaeological evidence suggests that the NWHI serves as a good proxy for past lightly exploited baselines in the MHI, thus supporting the validity of the space-for-time approach used above (Longenecker et al., 2014).

Endemism is remarkably high for shallow reef fishes throughout the archipelago, particularly in the NWHI where endemic species account for 30% of the species present and more than 52% of the numerical standing stock (DeMartini and Friedlander, 2004). Surveys of mesophotic coral reef depths (30–90 m) across the NWHI reveal average endemism of 46% with the relative abundances of endemic reef fishes on mesophotic reefs ranging from 16% at the southernmost end of the NWHI to upwards of 92% at the northernmost end of the NWHI (Kane et al., 2014). This unprecedented level of endemism indicates that mesophotic reefs in the NWHI are reservoirs of biodiversity, and of high conservation value.

PMNM has value as a reference area to assess individual fish stocks and provides guidance for fisheries management in the MHI. Using the NWHI as a reference, an assessment of fish stocks found that over one-quarter (27%) of fished species in the MHI were critically depleted (<10% of unfished abundance) and 42% were below 25% of unfished abundance, which is often considered a threshold for overfishing (Friedlander et al., 2008, 2014).

2.5.3 Socio-economic performance

Interest in commercialization of nearshore fisheries in the NWHI increased in the 1970s with the discovery of the potential for a profitable lobster fishery. Subsequently, the lobster fishery and a bottomfish fishery focusing on demersal species became active in the nearshore ecosystem (Kittinger et al., 2010). Pelagic fisheries also operate in and around the NWHI, but outside of the 50 nautical mile protected area. The lobster fishery became the most lucrative single fishery in the late 1980s but then underwent a steep decline beginning in the early 1990s, eventually leading to a 1-year closure in 1993 (Townsend and Pooley, 1995), then a permanent closure in 2000 with the establishment of the NWHI Coral Reef Ecosystem Reserve. Relative to the overall economy in Hawai'i and even in terms of commercial fisheries, the NWHI bottomfish fishery was rather small; nevertheless, the proposal to close it was controversial. One of the arguments against closure was the importance of the fishery to Hawai'i's economy, providing jobs in commercial fishing and supplying bottomfish to seafood retailers and restaurants. Because demand for Hawai'i-caught bottomfish was found to be highly elastic and widespread substitution with imports, the overall economic loss was quite small (Coffman and Kim, 2009).

Using information gathered from a representative subset of MPAs worldwide, McCrea-Strub et al. (2011) showed that variation in MPA startup costs was significantly related to both MPA size and the duration of the establishment phase. The largest MPA in the sample, PMNM, was also the most expensive to establish ($34.8 million; 2005) (McCrea-Strub et al., 2011). Over 99% of funding was provided by national NGOs and governmental agencies and approximately 20% of the total cost of establishment was allocated towards a compensation programme for NWHI commercial bottomfish and lobster fishermen who were displaced by the creation of PMNM (Kittinger et al., 2011).

2.5.4 Overview and future prospects

Marine ecosystems of the NWHI are being altered by direct effects of climate change including ocean warming, ocean acidification, rising sea level, changing circulation patterns, and increasing severity of storms (Keller et al., 2009). Direct anthropogenic threats include marine debris, ship-based pollution and strike risks, and alien species. Selkoe et al. (2009) mapped impacts in the NWHI and found that ocean temperature variation associated with disease outbreaks had the highest predicted impact overall, followed closely by other climate-related threats.

To address these and other management concerns, PMNM in cooperation with NOAA, USFWS, the State of Hawai'i, the NWHI Coral Reef Ecosystem Reserve Advisory Council, and others worked to design a plan to protect the living, cultural, and historical resources of the region as a public trust (PMNM, 2008). The public played a vital role in shaping the management plan for the proposed national marine sanctuary in the NWHI. This process formally began with public scoping meetings in 2002 and formed the basis for comprehensive management planning for the monument.

The management framework for the monument includes key elements to move towards ecosystem-based management, requiring implementation of multiple steps in a comprehensive and coordinated way. These elements include the legal and policy basis for establishment; the vision, mission, and guiding principles that provide the overarching policy direction; institutional arrangements between co-trustees and other stakeholders; regulations and zoning to manage human activities and threats; goals to guide implementation of action plans and priority management needs; and concepts and direction for moving towards a co-ordinated ecosystem approach to management (PMNM, 2008).

3. DISCUSSION

The case studies of different types of marine spatial management in Hawai'i presented in this chapter encompass a range of scales (Figure 5.7). The concept of scale is critical and influences many aspects of marine spatial management from ecology to human dimensions to governance. Different management objectives are best addressed by different scales of management. An understanding of the effects of scale for MPAs and MPA network design is vital to achieving success in implementation and effectiveness of these managed areas.

Successful MPA implementation and management require a balance between human uses and conservation objectives. Often MPA planning does not sufficiently address human activities in the marine space by failing to fully engaging all stakeholders early and throughout the process (Charles and Wilson, 2009; Mascia, 2003; Stewart et al., 2011). This has been a deficiency of marine spatial management in Hawai'i as it has elsewhere in the

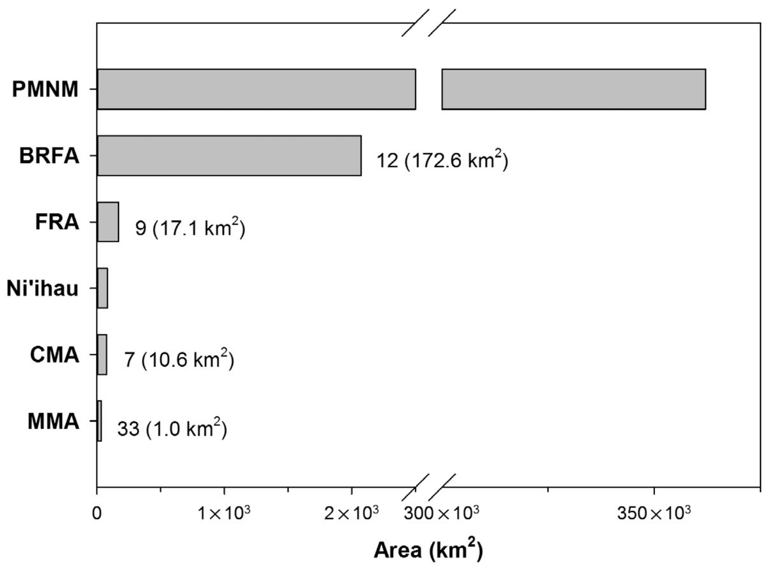

Figure 5.7 Comparison of total area for different types of spatial marine management in Hawai'i. For categories where $N > 1$, the number of MPAs is shown to the right of the bar with average area in parentheses. PMNM, Papahānaumokuākea Marine National Monument; BRFA, bottomfish restricted fishing areas; FRA, West Hawaii Fish Replenishment Areas; Ni'ihau, the island of Ni'ihau; CMA, co-management areas; and MMA, marine managed areas.

world (Tissot et al., 2009). Other shortcomings in MPA planning in Hawai'i and beyond include mismatches of MPA scale to issues and context, inadequate attention to compliance, failure due to degradation of the surrounding ecosystem, and damaging displacement of fishing effort (Agardy et al., 2011; Bergseth et al., 2013; Crowder et al., 2006). The State of Hawai'i has several MMA designations, with various goals surrounding conservation, fisheries management, and multi-use objectives (Figure 5.2A). However, while many of these areas are showing success, most are too small to achieve meaningful benefits outside their boundaries. Furthermore, because there has not been enough focus on compliance and enforcement, the modest successes of these areas are also being eroded by illegal, unreported, and unregulated fishing.

In contrast, community managed areas in Hawai'i are currently undergoing a renaissance. Despite CBSFA legislation, a functional approach to co-management has yet to be achieved; therefore, implementation of these areas has been through an entirely bottom-up approach that has been slow and arduous (Higuchi, 2008; Kittinger et al., 2012). In some cases, the context and objectives for these areas are dependent on the active members of the community, sometimes to the exclusion of other stakeholders or the broader context within which these community managed areas operate (Levine and Richmond, 2014). The West Hawai'i FRA network was based on a collaborative process involving a number of stakeholders. Though it has only been moderately successful in terms of reducing conflict between user groups, it has been very effective in achieving its ecological and economic goals (Stevenson and Tissot, 2013; Tissot et al., 2009). One advantage in the implementation process was that it was limited in scope, only addressing one small fishery (aquarium fish). Nevertheless, it is the best example in Hawai'i of an inclusive, collaborative, stakeholder-driven, participatory MPA planning process.

The BRFAs are similar to the FRA network in that the objectives were focused on only one fishery (bottomfish), however, that is where the similarities end. BRFA design and implementation was a top-down approach wherein DAR-designated areas based on pressure from the WPRFMC with little or no stakeholder involvement or adequate ecological data. While the system has since been evaluated and improved based on better understanding and mapping of bottomfish habitats, there has been little to no stakeholder involvement and fishermen are concerned about the perceived lack of science informing BRFA placement and evaluation of efficacy, as well as expressing frustration over the dearth of enforcement (Hospital and

Beavers, 2014). The establishment of the PMNM was a long process summarized previously in this chapter. This is another example of a top-down approach, though via the federal government rather than the state. A simplifying factor was the lack of human habitation in the area, and the few commercial fishing interests were well compensated for ceasing their activities. Governance of this area is complex but well addressed by Kittinger et al. (2010a). By virtue of its size and remoteness, PMNM by most measures is an unqualified success, while the situation in the MHI is a great deal more complicated.

3.1. Effects of scale

3.1.1 Ecological

One of the most important concepts related to scale of MPAs is the biology and ecology of the marine organisms which are to be protected. Neighbourhood sizes of both adult and larval life phases will have direct bearing on the ability of an MPA to protect a given species or suite of species (Palumbi, 2004). Pelagic species can move thousands of kilometers annually, while many reef fishes have home ranges <1 km (Alerstam et al., 2003; Block et al., 2001; Palumbi, 2004). Larval neighbourhood sizes can be even larger than these adult neighbourhoods, but recent studies using genetic and micro-chemical analyses of larval spread show cases where local retention of larvae is surprisingly high, suggesting that marine populations are not universally open over large geographic scales (Palumbi, 2004).

In a review of dispersal distance of propagules of benthic marine organisms, Shanks et al. (2003) showed a bimodal distribution suggesting two evolutionarily stable dispersal strategies: short-distance (<1 km) and long-distance (>20 km). Based on this, they recommend that reserves be designed large enough to contain the short-distance dispersing propagules and be spaced far enough apart that long-distance dispersing propagules released from one reserve can settle in adjacent reserves. The mean area of fully protected MLCDs in Hawai'i ($N=8$) is only 0.26 km^2, likely inhibiting self-recruitment and leaving these areas dependent on larval import. The FRA network however is much more in-line with these guidelines, with an average area of 12.8 km^2 and spaced 1–15 km apart over 150 km of coastline (Figures 5.7 and 5.2C). This design almost certainly promotes propagule sharing among FRAs, which likely contributes to the success of this MPA network in replenishing target species. Christie et al. (2010) found dispersal distances ranging from 15 to 184 km from a genetic parentage analysis of yellow tang confirming the export of larvae from West Hawai'i FRAs at this scale.

The larger the protected area, the smaller its border-to-area ratio, reducing the amount of "edge" habitat that is exposed to outside pressures (Keller et al., 2009; Woodroffe and Ginsberg, 1998). Although Stamoulis and Friedlander (2013) showed a fisheries spillover benefit from a small marine reserve in Hawai'i, small MPAs are unlikely to provide significant export of larvae and therefore the potential benefits to fisheries are limited. Furthermore, spillover of adult fishes from small reserves can reduce reproductive output with negative implications for stock enhancement (Sladek Nowlis and Roberts, 1999). Another drawback of small reserves is that they encompass a limited amount and variety of habitats and thus may not protect a full complement of marine species and/or all life stages of resident species (Palumbi, 2004; Sladek Nowlis and Friedlander, 2005). Thus, large-scale MPAs can be seen as maximizing the potential for achieving ecological objectives (Toonen et al., 2013).

While there are many factors at work, in general small-scale management units in Hawai'i such as community-based fishery managed areas, MLCDs, and FMAs will be able to protect sessile species, small benthic fishes, and some larger benthic fishes. Larger management units such as the West Hawai'i FRA network (if it were to eliminate all types of fishing) would be able to protect and enhance populations of most benthic fishes and some small pelagic species. The PMNM, however, is at a scale sufficient to protect the entire ecosystem including large pelagic fishes and migratory species. While ecologically this may be the most effective scale for spatial management, human dimensions including socio-economic and political considerations necessitate the use of smaller-scale spatial management units in populated locations such as the MHI.

3.1.2 Social

Spatial marine protection also has social goals that are linked with ecological objectives (Cinner et al., 2009b; Halpern et al., 2013; McClanahan et al., 2006; Rossiter and Levine, 2014). In order to promote success, the scale of protection should match the scale of the social, as well as ecological, outcomes desired (Charles and Wilson, 2009). To meet this challenge, researchers are developing innovative methods to assess the social attributes of ocean environments (Koehn et al., 2013), and ocean planning practitioners are increasingly engaging social data in planning practise to help spur inclusive planning processes that can engender better social and ecological outcomes (Kittinger et al., 2014; Le Cornu et al., 2014).

Such approaches will also have to consider the existing institutions, enabling environment, and MMA designations in a given geography. In Hawaii, MLCDs were designed to preserve and replenish marine life, providing opportunities for the public to interact with the marine environment and are popular sites for snorkelling, diving, and underwater photography. FMAs were designed to resolve conflicts among users including fishermen. While the scale of MLCDs ($\overline{X} = 0.35\,\mathrm{km}^2$) and FMAs ($\overline{X} = 0.72\,\mathrm{km}^2$) are quite small, they are generally sufficient to address their ecological and social objectives. If they were designed to benefit fisheries, a larger scale would be necessary. These MMAs and other areas can be scaled to meet both social and ecological objectives through a systematic approach to assess the cumulative impacts of current activities, the historical condition and current trajectory of nearshore ecosystems, and the current ecological and socioeconomic performance of existing management approaches.

Another critical aspect of MPA scale is the extent of the costs and benefits and the number of people affected. Naturally, the larger the MPA or MPA network, the more people will be impacted (Pollnac and Seara, 2011). The loss of fishing areas is often the primary public concern when implementing MPAs and many fishers in Hawai'i are vehemently opposed to them for this reason. Displacing too many fishers can introduce significant social and economic costs and make MPA establishment politically untenable (Jones, 2009). MPAs tend to have concentrated costs and disbursed benefits producing inequitable social impacts (Halpern et al., 2013). While large MPAs are known to produce ecological benefits across broad scales which benefit a range of ocean users, the costs will be concentrated among a relatively small group of fishermen. This holds true in Hawai'i and one of the guidelines the State of Hawai'i uses when evaluating areas for MLCD designation is that they are '... small enough so that fishermen are not denied the use of unreasonably vast fishing areas' (Division of Aquatic Resources, 2014). For the BFRAs on the other hand, continued pressure from fishermen and WPRFMC may result in the decision to open 6 of the 12 BRFAs to fishing. Due to the remoteness of the NWHI, the economic and social costs of establishing the PMNM were quite low compared to the benefits of designating the world's largest (at the time) MPA (Coffman and Kim, 2009; McCrea-Strub et al., 2011).

For land-related resource systems, very large territories are unlikely to be self-organized given the high costs of management, while small territories do not generate significant flows of valuable products. Thus, moderate-sized areas are most conducive to self-organization (Chhatre and Agrawal, 2008; Ostrom, 2009). Fishers who consistently utilize moderately sized coastal zones are also more likely to organize (Wilson et al., 2007) than fishers who target pelagics in the open ocean (Berkes et al., 2006). This seems to hold true for spatial marine protection strategies in Hawai'i, where government was responsible for implementing MMAs at very large and very small scales (the federal PMNM and state MMAs). However, at intermediate scales, community-based managed areas and the FRA network are both examples of self-organization, or bottom-up approaches, which are gaining momentum across the state.

To ensure success, MPA scale should not exceed institutional capacity (Christie et al., 2009). BRFAs are a case in Hawai'i where the scale exceeds the capacity of DLNR to manage, and enforcement is not occurring. For very large MPAs such as PMNM, the costs of management are proportionate to the spatial scale and likely beyond the capacity of any single institution or government agency. This MPA encompasses a range of institutional jurisdictions, thus a new model of institutional collaborative governance was created (Kittinger et al., 2011). Since the 2010 Convention on Biological Diversity and the establishment of the Aichi Biodiversity targets of protecting at least 10% of coastal and marine areas by 2020, large-scale MPAs have begun to proliferate and ocean governance is moving towards increased collaboration among countries as well as institutions (Toonen et al., 2013). In economic terms, large MPAs are more efficient in terms of establishment and maintenance costs. Though the overall cost to establish the PMNM was higher than any other MPA at the time, the cost per km^2 was among the lowest (McCrea-Strub et al., 2011). Furthermore, the long-term cost of MPA maintenance per km^2 drops significantly as size increases, providing broad economic, conservation, and scientific benefits (Toonen et al., 2013).

3.2. Hawaiian MPAs in the context of large-scale marine spatial planning

There exists in the MHI a patchwork of spatial marine management across a range of scales (Figures 5.1 and 5.7), with varying degrees of effectiveness. With the exception of co-management areas and the FRAs, stakeholder engagement is largely lacking for these management schemes and their efficacy is in question due to a combination of factors including lack of local support and non-compliance inside the boundaries, and ongoing impacts outside. Furthermore, this collection of MMAs does not ensure connectivity among sites, which is crucial to maintaining populations of mobile species and vital connections between local ecosystems, and does not recognize important processes originating offshore that provide linkages between coastal areas (Gaines et al., 2010). Finally, this patchwork of management areas cannot address the full suite of stressors that impact the marine populations and ecosystems in Hawai'i. In order to properly address the many impacts and competing objectives of a myriad of stakeholders, a larger vision is required (Tissot et al., 2009). One which could leverage the attention and resources currently being spent trying to protect this collection of discrete and rather small areas. One solution is a strategic, coordinated, and comprehensive planning effort that could be supported by robust and targeted management within discreet MPAs for which the sum total, within the context of the wider strategic marine plan, could drive effective ecosystem-based management. MSP provides a framework to achieve this goal (Agardy et al., 2011; Ehler and Douvere, 2009; Foley et al., 2010; Gopnick, 2008).

A coordinated, regional plan is not only necessary because of the large scale over which ecosystem dynamics, resource markets, and governance systems operate, but it is also likely more efficient and cost effective (e.g. Kark et al., 2009). MSP does not stand alone; rather it emerges from and builds on existing management frameworks such as integrated coastal management and ecosystem-based management. While regional planning is vital, effective implementation will always occur at the local level. Therefore, balancing the dynamics of regional and local level planning is essential for success (Agardy et al., 2011).

The Hawaiian Islands are an ideal location to apply the MSP framework. There exists an abundance of quality ecological data and the collection of human use data for marine spaces has been prioritized. The Bureau of Ocean Energy Management is currently compiling existing marine ecological data and collecting marine human use data to inform coastal zone planning and management strategies and for analysis of future offshore renewable energy programmes.

4. CONCLUSIONS

There is much resistance to the establishment of MPAs from the fishing sector for a variety of reasons including: loss of fishing areas, displacement or marginalization of subsistence fishers, perceived loss of income and cultural access, and the long lag time before benefits are realized (Cinner et al., 2009a; McClanahan et al., 2005; Pauly, 2009). Although not a panacea for marine fisheries management, MPAs in conjunction with other input and output controls are critical to sustaining fisheries and maintaining ecosystem health.

Spatial management of fisheries in Hawai‘i exists along a range of scales (Figure 5.7), and as exemplified by the BRFAs, bigger is not necessarily better. A critical theme underlying MPA success is the participatory nature of the planning process. To put it simply, MPAs which engage stakeholders early and often in the planning process tend to be more effective at achieving ecological and social goals (Agardy et al., 2011; Cinner, 2007; Mascia, 2003; McClanahan et al., 2006). This is exemplified by the community-based co-management areas in Hawai‘i and by the FRA network which was created through a stakeholder-driven, participatory process (Stevenson and Tissot, 2013).

Because social costs of MPAs tend to be concentrated while the benefits are disbursed, it is difficult to maintain social equity, especially for larger MPAs (Halpern et al., 2013; Lowry et al., 2009). Larger scales correspond to large numbers of stakeholders at increasing levels of organization (Agrawal, 2001; Baland and Platteau, 1996; Lowry et al., 2009). Thus governance structures need to make better use of the human capacity for complex normative frameworks to ensure that management requirements do not exceed institutional capacity (Christie et al., 2009; Kittinger et al., 2011). The BRFA system in Hawai‘i is a case where the scale of management created an imbalance in social equity, and because planning and management requirements exceeded institutional capacity, stakeholder confidence eroded to the point where the state was pressured to open 6 of the 12 areas to fishing.

The establishment of PMNM is a great achievement and an unqualified success by most measures. While the total cost of implementation was extreme, the cost per unit area was among the lowest in Hawai‘i, as are the long-term maintenance costs. While large-scale marine reserves provide our best hope for arresting the global decline in biodiversity and addressing global fisheries collapse (Toonen et al., 2013), they are simply not applicable in populated areas such as the MHI. Properly implemented MSP is necessary to balance conservation and social objectives in these complex, socio-ecological systems and achieve effective, equitable, and sustainable outcomes (Agardy et al., 2011; Douvere, 2008; Halpern et al., 2008).

REFERENCES

Agardy, T., di Sciara, G.N., Christie, P., 2011. Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. Mar. Policy 35, 226–232. http://dx.doi.org/10.1016/j.marpol.2010.10.006.

Agrawal, A., 2001. Common property institutions and sustainable governance of resources. World Dev. 29, 1649–1672. http://dx.doi.org/10.1016/S0305-750X(01)00063-8.

Alerstam, T., Hedenström, A., Åkesson, S., 2003. Long-distance migration: evolution and determinants. Oikos 103, 247–260. http://dx.doi.org/10.1034/j.1600-0706.2003.12559.x.

Andrews, A.H., DeMartini, E.E., Brodziak, J., Nichols, R.S., Humphreys, R.L., 2012. A long-lived life history for a tropical, deepwater snapper (*Pristipomoides filamentosus*): bomb radiocarbon and lead–radium dating as extensions of daily increment analyses in otoliths. Can. J. Fish. Aquat. Sci. 69, 1850–1869. http://dx.doi.org/10.1139/f2012-109.

Antolini, D., Moffie, K., Paulson, D., 2003. Hawaii marine protected areas governance study. (Commissioned report). State Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu, HI.

Antonelis, G.A., Baker, J.D., Johanos, T.C., Braun, R.C., Harting, A.L., 2006. Hawaiian monk seal (*Monachus schauinslandi*): status and conservation issues. Atoll Res. Bull. 543, 75–101.

Ayers, A.L., Kittinger, J.N., 2014. Emergence of co-management governance for Hawai'i coral reef fisheries. Global Environ. Change 28, 251–262. http://dx.doi.org/10.1016/j.gloenvcha.2014.07.006.

Baland, J.-M., Platteau, J.-P., 1996. Halting Degradation of Natural Resources: Is There a Role for Rural Communities? Food & Agriculture Org, Rome, Italy.

Bell, F.T., Higgens, E., 1939. A plan for the development of the Hawaiian fisheries. (Investigational report no. 4). US Bureau of Fisheries, Washington, DC.

Bell, J.D., Johnson, J.E., Hobday, A.J., 2011. Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, Noumea, New Caledonia.

Bergseth, B.J., Russ, G.R., Cinner, J.E., 2013. Measuring and monitoring compliance in no-take marine reserves. Fish Fish. n/a–n/a. http://dx.doi.org/10.1111/faf.12051.

Berkes, F., 2010. Devolution of environment and resources governance: trends and future. Environ. Conserv. 37, 489–500. http://dx.doi.org/10.1017/S037689291000072X.

Berkes, F., Hughes, T.P., Steneck, R.S., Wilson, J.A., Bellwood, D.R., Crona, B., Folke, C., Gunderson, L.H., Leslie, H.M., Norberg, J., Nyström, M., Olsson, P., Österblom, H., Scheffer, M., Worm, B., 2006. Globalization, roving bandits, and marine resources. Science 311, 1557–1558. http://dx.doi.org/10.1126/science.1122804.

Block, B.A., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Seitz, A., Walli, A., Fudge, D., 2001. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. Science 293, 1310–1314. http://dx.doi.org/10.1126/science.1061197.

Bowen, B.W., Meylan, A.B., Ross, T.P., Limpus, C.T., 1992. Global population structure and natural history of the green turtle (*Chelonia mydas*) in terms of matriarchal phylogeny. Evolution 46, 865–881.

Briggs, J.C., Bowen, B.W., 2012. A realignment of marine biogeographic provinces with particular reference to fish distributions. J. Biogeogr. 39, 12–30. http://dx.doi.org/10.1111/j.1365-2699.2011.02613.x.

Capitini, C.A., Tissot, B.N., Carroll, M.S., Walsh, W.J., Peck, S., 2004. Competing perspectives in resource protection: the case of marine protected areas in West Hawai'i. Soc. Nat. Resour. 17, 763–778. http://dx.doi.org/10.1080/08941920490493747.

Cesar, H.S.J., van Beukering, P., 2004. Economic valuation of the coral reefs of Hawai'i. Pac. Sci. 58, 231–242. http://dx.doi.org/10.1353/psc.2004.0014.
Chaloupka, M., Balazs, G., 2007. Using Bayesian state-space modelling to assess the recovery and harvest potential of the Hawaiian green sea turtle stock. Ecol. Model. 205, 93–109. http://dx.doi.org/10.1016/j.ecolmodel.2007.02.010.
Charles, A., Wilson, L., 2009. Human dimensions of Marine Protected Areas. ICES J. Mar. Sci. 66, 6–15. http://dx.doi.org/10.1093/icesjms/fsn182.
Chave, E.H., Mundy, B.C., 1994. Deep-sea benthic fish of the hawaiian Archipelago, Cross Seamount, and Johnston Atoll. Pac. Sci. 48, 367–409.
Chhatre, A., Agrawal, A., 2008. Forest commons and local enforcement. Proc. Natl. Acad. Sci. U.S.A. 105, 13286–13291. http://dx.doi.org/10.1073/pnas.0803399105.
Christie, P., Pollnac, R.B., Oracion, E.G., Sabonsolin, A., Diaz, R., Pietri, D., 2009. Back to basics: an empirical study demonstrating the importance of local-level dynamics for the success of tropical marine ecosystem-based management. Coast. Manag. 37, 349–373. http://dx.doi.org/10.1080/08920750902851740.
Christie, M.R., Tissot, B.N., Albins, M.A., Beets, J.P., Jia, Y., Ortiz, D.M., Thompson, S.E., Hixon, M.A., 2010. Larval connectivity in an effective network of marine protected areas. PLoS ONE 5, e15715. http://dx.doi.org/10.1371/journal.pone.0015715.
Cinner, J.E., 2007. Designing marine reserves to reflect local socioeconomic conditions: lessons from long-enduring customary management systems. Coral Reefs 26, 1035–1045. http://dx.doi.org/10.1007/s00338-007-0213-2.
Cinner, J.E., Aswani, S., 2007. Integrating customary management into marine conservation. Biol. Conserv. 140, 201–216. http://dx.doi.org/10.1016/j.biocon.2007.08.008.
Cinner, J.E., Daw, T., McClanahan, T.R., 2009a. Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. Conserv. Biol. 23, 124–130. http://dx.doi.org/10.1111/j.1523-1739.2008.01041.x.
Cinner, J.E., McClanahan, T.R., Daw, T.M., Graham, N.A.J., Maina, J., Wilson, S.K., Hughes, T.P., 2009b. Linking social and ecological systems to sustain coral reef fisheries. Curr. Biol. 19, 206–212. http://dx.doi.org/10.1016/j.cub.2008.11.055.
Claisse, J.T., Kienzle, M., Bushnell, M.E., Shafer, D.J., Parrish, J.D., 2009. Habitat-and sex-specific life history patterns of yellow tang *Zebrasoma flavescens* in Hawaii, USA. Mar. Ecol. Prog. Ser. 389, 245–255.
Clark, M.R., Koslow, J.A., 2008. Impacts of fisheries on seamounts. In: Pitcher, T.J. (Ed.), Seamounts: Ecology, Fisheries & Conservation. Blackwell Pub, Oxford; Ames, Iowa, p. 413.
Cobb, J.N., 1901. Commercial fisheries of the Hawaiian Islands. (U.S. Fish Commission Report for 1901). Government Printing Office, Washington, DC.
Coffman, M., Kim, K., 2009. The economic impacts of banning commercial bottomfish fishing in the Northwestern Hawaiian Islands. Ocean Coast. Manage. 52, 166–172. http://dx.doi.org/10.1016/j.ocecoaman.2008.12.003.
Crowder, L.B., Osherenko, G., Young, O.R., Airamé, S., Norse, E.A., Baron, N., Day, J.C., Douvere, F., Ehler, C.N., Halpern, B.S., 2006. Resolving mismatches in US ocean governance. Science 313, 617–618.
Dawson, T., 2014. Abercrombie signs West Hawaii fishing rules. Environ. Hawaii 24, 12 (Gov).
DeMartini, E.E., Friedlander, A.M., 2004. Spatial patterns of endemism in shallow-water reef fish populations of the Northwestern Hawaiian Islands. Mar. Ecol. Prog. Ser. 271, 281–296.
DeMartini, E.E., Friedlander, A.M., 2006. Predation, endemism, and related processes structuring shallow-water reef fish assemblages of the NWHI. Atoll Res. Bull. 543, 237–256.
DeMartini, E.E., Friedlander, A.M., Holzwarth, S.R., 2005. Size at sex change in protogynous labroids, prey body size distributions, and apex predator densities at NW Hawaiian atolls. Mar. Ecol. Prog. Ser. 297, 259–271.

Division of Aquatic Resources, 1992. Marine Life Conservation District Plan. Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu, HI.

Division of Aquatic Resources, 2014. Hawaii Marine Life Conservation Districts. http://state.hi.us/dlnr/dar/mlcd.html.

Dollar, S.J., 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1, 71–81. http://dx.doi.org/10.1007/BF00301688.

Douvere, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar. Policy 32, 762–771. http://dx.doi.org/10.1016/j.marpol.2008.03.021.

Drazen, J.C., Haedrich, R.L., 2012. A continuum of life histories in deep-sea demersal fishes. Deep-Sea Res. I Oceanogr. Res. Pap. 61, 34–42. http://dx.doi.org/10.1016/j.dsr.2011.11.002.

Drazen, J.C., Moriwake, V., Demarke, C., Alexander, B., Misa, W., Yeh, J., 2010. Assessing Kaho'olawe Island Reserve's bottomfish populations: a potential benchmark for main Hawaiian Island restricted fishing areas. Prepared for the Kahoolawe Island Reserve Commission. University of Hawaii, Honolulu, HI.

Ehler, C., Douvere, F., 2009. Marine Spatial Planning: A Step-by-Step Approach Toward Ecosystem-Based Management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. UNESCO, Paris.

Flament, P.J., Kennan, S.C., Knox, R.A., Niiler, P.P., Bernstein, R.L., 1996. The three-dimensional structure of an upper ocean vortex in the tropical Pacific Ocean. Nature 383, 610–613.

Foley, M.M., Halpern, B.S., Micheli, F., Armsby, M.H., Caldwell, M.R., Crain, C.M., Prahler, E., Rohr, N., Sivas, D., Beck, M.W., Carr, M.H., Crowder, L.B., Emmett Duffy, J., Hacker, S.D., McLeod, K.L., Palumbi, S.R., Peterson, C.H., Regan, H.M., Ruckelshaus, M.H., Sandifer, P.A., Steneck, R.S., 2010. Guiding ecological principles for marine spatial planning. Mar. Policy 34, 955–966. http://dx.doi.org/10.1016/j.marpol.2010.02.001.

Foley, M.M., Armsby, M.H., Prahler, E.E., Caldwell, M.R., Erickson, A.L., Kittinger, J.N., Crowder, L.B., Levin, P.S., 2013. Improving ocean management through the use of ecological principles and integrated ecosystem assessments. Bioscience 63, 619–631. http://dx.doi.org/10.1525/bio.2013.63.8.5.

Friedlander, A.M., 2004. Status of Hawaii's coastal fisheries in the new millennium, Revised 2004 edition, in: 2001 Fisheries Symposium. Presented at the 2001 Fisheries Symposium, American Fisheries Society, Hawaii Chapter.

Friedlander, A.M., DeMartini, E.E., 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar. Ecol. Prog. Ser. 230, 253–264.

Friedlander, A.M., Parrish, J.D., 1997. Fisheries harvest and standing stock in a Hawaiian Bay. Fish. Res. 32, 33–50.

Friedlander, A., Poepoe, K., Poepoe, K., Helm, K., Bartram, P., Maragos, J., Abbott, I., 2002. Application of Hawaiian traditions to community-based fishery management. In: Proceedings of the Ninth International Coral Reef Symposium, Bali, 23–27 October 2000, pp. 813–815.

Friedlander, A.M., Brown, E.K., Jokiel, P.L., Smith, W.R., Rodgers, K.S., 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs 22, 291–305. http://dx.doi.org/10.1007/s00338-003-0317-2.

Friedlander, A.M., Brown, E., Monaco, M.E., 2007a. Defining reef fish habitat utilization patterns in Hawaii: comparisons between marine protected areas and areas open to fishing. Mar. Ecol. Prog. Ser. 351, 221–233.

Friedlander, A.M., Brown, E.K., Monaco, M.E., 2007b. Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii. Ecol. Appl. 17, 715–730. http://dx.doi.org/10.1890/06-0536.

Friedlander, A., Aeby, G., Balwani, S., Bowen, B., Brainard, R., Clark, A., Kenyon, J., Maragos, J., Meyer, C., Vroom, P., Zcbeamzow, J., 2008. The state of coral reef ecosystems of the northwestern Hawaiian Islands. (NOAA Technical Memorandum No. NOS NCCOS 73). In: Waddell, J.E., Clarke, A.M. (Eds.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA/NCCOS Center of Coastal Monitoring and Assessment's Biogeography Team, Silver Spring, MD.

Friedlander, A.M., Nowlis, J., Koike, H., 2014. Improving fisheries assessments using historical data: stock status and catch limits. In: Kittinger, J.N., McClenachan, L., Gedan, K.B., Blight, L.K. (Eds.), Applying Marine Historical Ecology to Conservation and Management: Using the Past to Manage for the Future. University of California Press, pp. 91–118.

Friedlander, A.M., Shackeroff, J.M., Kittinger, J.N., 2013. Customary marine resource knowledge and use in contemporary Hawai'i. Pac. Sci. 67, 441–460. http://dx.doi.org/10.2984/67.3.10.

Gaines, S.D., White, C., Carr, M.H., Palumbi, S.R., 2010. Designing marine reserve networks for both conservation and fisheries management. Proc. Natl. Acad. Sci. U.S.A. 107, 18286–18293. http://dx.doi.org/10.1073/pnas.0906473107.

Geslani, C., Loke, M., Takenaka, B., Leung, P., 2012. Hawaii's Seafood Consumption and Its Supply Sources. Department of Natural Resources and Environmental Management, University of Hawaii, Manoa, Honolulu, HI.

Glazier, E.W., 2007. Hawaiian fishermen. In: Spindler, G., Stockard, J. (Eds.), Case Studies in Cultural Anthropology. Thomson-Wadsworth, Belmont, CA, p. 145.

Gopnick, M., 2008. Integrated Marine Spatial Planning in US Waters: The Path Forward. Marine Conservation Initiative of the Gordon and Betty Moore Foundation.

Gove, J.M., Williams, G.J., McManus, M.A., Heron, S.F., Sandin, S.A., Vetter, O.J., Foley, D.G., 2013. Quantifying climatological ranges and anomalies for Pacific coral reef ecosystems. PLoS ONE 8, e61974. http://dx.doi.org/10.1371/journal.pone.0061974.

Grigg, R.W., 1982. Darwin point: a threshold for atoll formation. Coral Reefs 1, 29–34. http://dx.doi.org/10.1007/BF00286537.

Grigg, R.W., 1983. Community structure, succession and development of coral reefs in Hawaii. Mar. Ecol. Prog. Ser. 11, 1–14.

Grigg, R.W., 1997. Paleoceanography of coral reefs in the Hawaiian-Emperor Chain—revisited. Coral Reefs 16, S33–S38. http://dx.doi.org/10.1007/s003380050239.

Grigg, R.W., Polovina, J., Friedlander, A.M., Rohmann, S.O., 2008. Biology of coral reefs in the Northwestern Hawaiian Islands. In: Riegl, B.M., Dodge, R.E. (Eds.), Coral Reefs of the USA, Coral Reefs of the World. Springer, The Netherlands, pp. 573–594.

Grorud-Colvert, K., Claudet, J., Tissot, B.N., Carr, M.H., Day, J.C., Friedlander, A.M., Lester, S.E., Lison de Loma, S.E., Malone, D., Walsh, W.J., 2014. Marine protected area networks: assessing whether the whole is greater than the sum of its parts? PLoS ONE 9 (8), e102298.

Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470, 386–389. http://dx.doi.org/10.1038/nature09689.

Haight, W.R., Parrish, J.D., Hayes, T.A., 1993. Feeding ecology of deepwater Lutjanid snappers at Penguin Bank, Hawaii. Trans. Am. Fish. Soc. 122, 328–347. http://dx.doi.org/10.1577/1548-8659(1993)122<0328:FEODLS>2.3.CO;2.

Halpern, B.S., McLeod, K.L., Rosenberg, A.A., Crowder, L.B., 2008. Managing for cumulative impacts in ecosystem-based management through ocean zoning. Ocean Coast. Manage. 51, 203–211. http://dx.doi.org/10.1016/j.ocecoaman.2007.08.002.

Halpern, B.S., Klein, C.J., Brown, C.J., Beger, M., Grantham, H.S., Mangubhai, S., Ruckelshaus, M., Tulloch, V.J., Watts, M., White, C., Possingham, H.P., 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proc. Natl. Acad. Sci. U.S.A. 110, 6229–6234. http://dx.doi.org/10.1073/pnas.1217689110.

Harrison, C.S., 1990. Seabirds of Hawaii: Natural History and Conservation. Cornell University Press, Ithaca, NY.

Hawai'i Administrative Rules (HAR), 2004. Hawaii State Legislature, Honolulu, HI (Chapter 13–94).

Hawaii Revised Statutes (HRS), 2005. Hawaii State Legislature, Honolulu, HI (Chapter 188–22.6).

Higuchi, J., 2008. Propagating cultural Kipuka: the obstacles and opportunities of establishing a community-based subsistence finishing area. U. Haw. L. Rev. 31, 193.

Hospital, J., Beavers, C., 2012. Economic and social characteristics of bottomfish fishing in the main Hawaiian islands. (Administrative report no H-12-01), NMFS-PIFSC, Honolulu, HI.

Hospital, J., Beavers, C., 2014. Catch shares and the main Hawaiian Islands bottomfish fishery: linking fishery conditions and fisher perceptions. Mar. Policy 44, 9–17. http://dx.doi.org/10.1016/j.marpol.2013.08.006.

Hospital, J., Bruce, S.S., Pan, M., 2011. Economic and social characteristics of the Hawaii small boat pelagic fishery. (Administrative report no. H-11-01), US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, HI.

'Ī'ī, J.P., 1993. Fragments of Hawaiian history. Bishop Museum Press, Honolulu, HI.

Johannes, R.E., 1978. Traditional marine conservation methods in oceania and their demise. Annu. Rev. Ecol. Syst. 9, 349–364. http://dx.doi.org/10.1146/annurev.es.09.110178.002025.

Johannes, R.E., 1981. Working with fishermen to improve coastal tropical fisheries and resource management. Bull. Mar. Sci. 31, 673–680.

Jokiel, P.L., 1987. Ecology, biogeography and evolution of corals in Hawaii. Trends Ecol. Evol. 2, 179–182. http://dx.doi.org/10.1016/0169-5347(87)90016-4.

Jones, P.J.S., 2009. Equity, justice and power issues raised by no-take marine protected area proposals. Mar. Policy 33, 759–765. http://dx.doi.org/10.1016/j.marpol.2009.02.009.

Jupiter, S.D., Weeks, R., Jenkins, A.P., Egli, D.P., Cakacaka, A., 2012. Effects of a single intensive harvest event on fish populations inside a customary marine closure. Coral Reefs 31, 321–334. http://dx.doi.org/10.1007/s00338-012-0888-x.

Juvik, S.P., Juvik, J.O., Paradise, T.R., 1998. Atlas of Hawaii. University of Hawaii Press, Honolulu, HI.

Kaha'ulelio, D., 2006. Ka Oihana Lawai'a: Hawaiian Fishing Traditions. Bishop Museum Press and Awaiaulu Press, Honolulu, HI.

Kamakau, S.M., 1976. The Works of the People of Old: Na hana a ka po'e kahiko. Bishop Museum Press, Honolulu, HI.

Kane, C., Kosaki, R.K., Wagner, D., 2014. High levels of mesophotic reef fish endemism in the Northwestern Hawaiian Islands. Bull. Mar. Sci. 90, 693–703. http://dx.doi.org/10.5343/bms.2013.1053.

Kaneshiro, K.Y., Chinn, P., Duin, K.N., Hood, A.P., Maly, K., Wilcox, B.A., 2005. Hawai'i's mountain-to-sea ecosystems: social–ecological microcosms for sustainability science and practice. Ecohealth 2, 349–360. http://dx.doi.org/10.1007/s10393-005-8779-z.

Kark, S., Levin, N., Grantham, H.S., Possingham, H.P., 2009. Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin. Proc. Natl. Acad. Sci. 106, 15368–15373. http://dx.doi.org/10.1073/pnas.0901001106.

Kay, A.E., Palumbi, S.R., 1987. Endemism and evolution in Hawaiian marine invertebrates. Trends Ecol. Evol. 2, 183–186. http://dx.doi.org/10.1016/0169-5347(87)90017-6.

Keller, B.D., Gleason, D.F., McLeod, E., Woodley, C.M., Airamé, S., Causey, B.D., Friedlander, A.M., Grober-Dunsmore, R., Johnson, J.E., Miller, S.L., Steneck, R.S., 2009. Climate change, coral reef ecosystems, and management options for marine protected areas. Environ. Manag. 44, 1069–1088. http://dx.doi.org/10.1007/s00267-009-9346-0.

Kelley, C., Moffitt, R., Smith, J.R., 2006. Mega-to micro-scale classification and description of bottomfish essential fish habitat on four banks in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543, 319–332.

Kikiloi, K., Graves, M., 2010. Rebirth of an archipelago: sustaining a Hawaiian cultural identity for people and homeland. Hulili 6, 73–114.

Kirch, P.V., 1989. The Evolution of the Polynesian Chiefdoms. Cambridge University Press, Cambridge, England.

Kittinger, J.N., 2010. Historical ecology of coral reefs in the Hawaiian Archipelago (Ph.D. dissertation). University of Hawaii, Honolulu, HI.

Kittinger, J.N., 2013. Participatory fishing community assessments to support coral reef fisheries comanagement. Pac. Sci. 67, 361–381. http://dx.doi.org/10.2984/67.3.5.

Kittinger, J.N., Dowling, A., Purves, A.R., Milne, N.A., Olsson, P., 2011. Marine Protected Areas, Multiple-Agency Management, and Monumental Surprise in the Northwestern Hawaiian Islands. J. Mar. Bio. 2011, 17 pages. Article ID 241374, http://dx.doi.org/10.1155/2011/241374.

Kittinger, J.N., Duin, K.N., Wilcox, B.A., 2010. Commercial fishing, conservation and compatibility in the Northwestern Hawaiian Islands. Mar. Policy 34, 208–217. http://dx.doi.org/10.1016/j.marpol.2009.06.007.

Kittinger, J.N., Ayers, A.L., Prahler, E.E., 2012. Policy Briefing: Co-Management of Coastal Fisheries in Hawai'i: Overview and Prospects for Implementation. Stanford University, Center for Ocean Solutions & Department of Urban and Regional Planning, University of Hawaii, Manoa, Monterey, CA and Honolulu, HI.

Kittinger, J.N., Koehn, J.Z., Le Cornu, E., Ban, N.C., Armsby, M., Brooks, C., Carr, M.H., Cinner, J.E., Cravens, A., D'iorio, M., Erickson, A., Finkbeiner, E.M., Foley, M.M., Fujita, R., Gelcich, S., Gopnick, M., Hazen, L.J., Lopuch, M., Martin, K.S., Prahler, E.E., Reineman, D.R., Shackeroff, J., White, C., Caldwell, M.R., Crowder, L.B., 2014. A practical approach for putting people into ecosystem-based ocean planning. Front. Ecol. Environ. http://dx.doi.org/10.1890/130267.

Koehn, J.Z., Reineman, D.R., Kittinger, J.N., 2013. Progress and promise in spatial human dimensions research for ecosystem-based ocean planning. Mar. Policy 42, 31–38. http://dx.doi.org/10.1016/j.marpol.2013.01.015.

Kosaki, R.H., 1954. Konohiki Fishing Rights. Legislative Reference Bureau, University of Hawaii, Honolulu, HI.

Le Cornu, E., Kittinger, J.N., Koehn, J.Z., Finkbeiner, E.M., Crowder, L.B., 2014. Current practice and future prospects for social data in coastal and ocean planning. Conserv. Biol. http://dx.doi.org/10.1111/cobi.12310.

Levine, A.S., Richmond, L.S., 2014. Examining enabling conditions for community-based fisheries comanagement: comparing efforts in Hawai'i and American Samoa. Ecol. Soc. 19, 24.

Lizaso, J.S., Goñi, R., Reñones, O., Charton, J.G., Galzin, R., Bayle, J.T., Jerez, P.S., Ruzafa, A.P., Ramos, A.A., 2000. Density dependence in marine protected populations: a review. Environ. Conserv. 27, 144–158.

Lobel, P.S., Robinson, A.R., 1986. Transport and entrapment of fish larvae by ocean mesoscale eddies and currents in Hawaiian waters. Deep-Sea Res. I Oceanogr. Res. Pap. 33, 483–500. http://dx.doi.org/10.1016/0198-0149(86)90127-5.

Longenecker, K., Chan, Y.L., Toonen, R.J., Carlon, D.B., Hunt, T.L., Friedlander, A.M., DeMartini, E.E., 2014. Archaeological evidence of validity of fish populations on unexploited reefs as proxy targets for modern populations. Conserv. Biol.
Lowe, M.K., 2004. The status of inshore fisheries ecosystems in the main Hawaiian Islands at the down of the millenium: cultural impacts, fisheries trends, and management challenges. In: Friedlander, A.M. (Ed.), Status of Hawaiis Coastal Fisheries in the New Millenium. Revised 2004 Edition, Proceedings of the 2001 Fisheries Symposium. American Fisheries Society, Hawaii Chapter, Honolulu, HI.
Lowry, K., Jarman, C., Maehara, S., 1990. Ocean management in Hawaii. Coast. Manag. 18, 233–254. http://dx.doi.org/10.1080/08920759009362113.
Lowry, G.K., White, A.T., Christie, P., 2009. Scaling up to networks of marine protected areas in the Philippines: biophysical, legal, institutional, and social considerations. Coast. Manag. 37, 274–290. http://dx.doi.org/10.1080/08920750902851146.
Malo, D., 1951. Hawaiian Antiquities: Moʻolelo Hawai'i. Bishop Museum Press, Honolulu, HI.
Maragos, J.E., Potts, D.C., Aeby, G.S., Gulko, D., Kenyon, J., Siciliano, D., VanRavenswaay, D., 2004. 2000–2002 rapid ecological assessment of corals (Anthozoa) on shallow reefs of the northwestern Hawaiian Islands. Part 1: species and distribution. Pac. Sci. 58, 211–230. http://dx.doi.org/10.1353/psc.2004.0020.
Papahānaumokuākea Marine National Monument, NOAA, FWS, DLNR, 2008. Papahānaumokuākea Marine National Monument Management Plan, Honolulu, HI.
Mascia, M.B., 2003. The human dimension of coral reef marine protected areas: recent social science research and its policy implications. Conserv. Biol. 17, 630–632.
McClanahan, T.R., Mangi, S., 2000. Spillover of expoitable fishes from a marine park and its effect on the adjacent fishery. Ecol. Appl. 10, 1792–1805. http://dx.doi.org/10.1890/1051-0761(2000) 010[1792:SOEFFA]2.0.CO;2.
McClanahan, T.R., Maina, J., Davies, J., 2005. Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. Fish. Manag. Ecol. 12, 105–112. http://dx.doi.org/10.1111/j.1365-2400.2004.00431.x.
McClanahan, T.R., Marnane, M.J., Cinner, J.E., Kiene, W.E., 2006. A comparison of marine protected areas and alternative approaches to coral-reef management. Curr. Biol. 16, 1408–1413. http://dx.doi.org/10.1016/j.cub.2006.05.062.
McClenachan, L., Kittinger, J.N., 2013. Multicentury trends and the sustainability of coral reef fisheries in Hawaiʻi and Florida. Fish Fish. 14, 239–255. http://dx.doi.org/10.1111/j.1467-2979.2012.00465.x.
McCrea-Strub, A., Zeller, D., Rashid Sumaila, U., Nelson, J., Balmford, A., Pauly, D., 2011. Understanding the cost of establishing marine protected areas. Mar. Policy 35, 1–9. http://dx.doi.org/10.1016/j.marpol.2010.07.001.
McGregor, D., 2007. Na Kuaʻaina: Living Hawaiian Culture. University of Hawaii Press, Honolulu, HI.
McGregor, D.P., Minerbi, L., Matsuoka, J., 1998. A holistic assessment method of health and well-being for Native Hawaiian communities. Pac. Health Dialog 5, 361–369.
McGregor, D., Morelli, P., Matsuoka, J., Rodenhurst, R., Kong, N., Spencer, M., 2003. An ecological model of Native Hawaiian well-being. Pac. Health Dialog 10, 106–128.
Merritt, D., Donovan, M.K., Kelley, C., Waterhouse, L., Parke, M., Wong, K., Drazen, J.C., 2011. BotCam: a baited camera system for non-extractive monitoring of bottomfish species. Fish. Bull. 109, 56–67.
Moffitt, R.B., Kobayashi, D.R., DiNardo, G.T., 2006. Status of the Hawaiian bottomfish stocks, 2004. (Administrative Report). National Marine Fisheries Service, Honolulu, HI.
Molloy, P.P., McLean, I.B., Côté, I.M., 2009. Effects of marine reserve age on fish populations: a global meta-analysis. J. Appl. Ecol. 46, 743–751. http://dx.doi.org/10.1111/j.1365-2664.2009.01662.x.

Moore, C.H., Drazen, J.C., Kelley, C.D., Misa, W.F.X.E., 2013. Deepwater marine protected areas of the main Hawaiian Islands: establishing baselines for commercially valuable bottomfish populations. Mar. Ecol. Prog. Ser. 476, 167–183. http://dx.doi.org/10.3354/meps10132.

Myers, R.A., Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. Nature 423, 280–283. http://dx.doi.org/10.1038/nature01610.

Myers, R.A., Worm, B., 2005. Extinction, survival or recovery of large predatory fishes. Philos. Trans. R. Soc., B 360, 13–20. http://dx.doi.org/10.1098/rstb.2004.1573.

National Marine Fisheries Service, 2014. Fisheries economics of the United States: 2012. (NOAA Technical Memorandum No. NMFS-F/SPO-137). US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Pacific Islands Fisheries Science Center.

Needham, M.D., Tynon, J.F., Ceurvorst, R.L., Collins, R.L., Connor, W.M., Culnane, M.J.W., 2008. Recreation carrying capacity and management at Pupukea Marine Life Conservation District on Oahu, Hawaii, (Final project report for Hawaii Division of Aquatic Resources, Department of Land and Natural Resources). Oregon State University, Department of Forest Ecosystems and Society, Corvallis, OR.

Ortiz, D.M., Tissot, B.N., 2008. Ontogenetic patterns of habitat use by reef-fish in a Marine Protected Area network: a multi-scaled remote sensing and in situ approach. Mar. Ecol. Prog. Ser. 365, 217–232.

Ortiz, D.M., Tissot, B.N., 2012. Evaluating ontogenetic patterns of habitat use by reef fish in relation to the effectiveness of marine protected areas in West Hawaii. J. Exp. Mar. Biol. Ecol. 432–433, 83–93. http://dx.doi.org/10.1016/j.jembe.2012.06.005.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422. http://dx.doi.org/10.1126/science.1172133.

Ostrom, E., Janssen, M.A., Anderies, J.M., 2007. Going beyond panaceas. Proc. Natl. Acad. Sci. 104 (39), 15176–15178.

Palumbi, S.R., 2004. Marine reserves and ocean neighborhoods: the spatial scale of marine populations and their management. Annu. Rev. Environ. Resour. 29, 31–68. http://dx.doi.org/10.1146/annurev.energy.29.062403.102254.

Pandolfi, J.M., Jackson, J.B., Baron, N., Bradbury, R.H., Guzman, H.M., Hughes, T.P., Kappel, C.V., Micheli, F., Ogden, J.C., Possingham, H.P., 2005. Are U. S. coral reefs on the slippery slope to slime? Science 307, 1725–1726.

Parke, M., 2007. Linking Hawaii fisherman reported commercial bottomfish catch data to potential bottomfish habitat and proposed restricted fishing areas using GIS and spatial analysis. (NOAA Technical Memorandum). National Marine Fisheries Service, Honolulu, HI.

Pauly, D., 2009. Beyond duplicity and ignorance in global fisheries. Sci. Mar. 73, 215–224. http://dx.doi.org/10.3989/scimar.2009.73n2215.

Poepoe, K., Bartram, P., Friedlander, A., 2007. The use of traditional Hawaiian knowledge in the contemporary management of marine resources. In: Haggan, N., Neis, B., Baird, I. (Eds.), Fishers' Knowledge in Fisheries Science and Management. UNESCO, Paris, France, pp. 117–141.

Pollnac, R., Seara, T., 2011. Factors influencing success of marine protected areas in the Visayas, Philippines as related to increasing protected area coverage. Environ. Manag. 47, 584–592. http://dx.doi.org/10.1007/s00267-010-9540-0.

Pooley, S.G., 1993. Hawai'i's marine fisheries: some history, long-term trends, and recent developments. Mar. Fish. Rev. 55, 7–19.

Ralston, C., 1984. Hawaii 1778–1854: some aspects of Maka'ainana response to rapid cultural change. J. Pac. Hist. 19, 21–40. http://dx.doi.org/10.1080/00223348408572478.

Randall, J.E., 1998. Zoogeography of shore fishes of the Indo-Pacific region. Zool. Stud. 37, 227–268.

Rossiter, J.S., Levine, A., 2014. What makes a "successful" marine protected area? The unique context of Hawaii′s fish replenishment areas. Mar. Policy 44, 196–203. http://dx.doi.org/10.1016/j.marpol.2013.08.022.

Ruddle, K., 1996. Traditional management of reef fishing. In: Polunin, N.V.C., Roberts, C.M. (Eds.), Reef Fisheries. In: Chapman & Hall Fish and Fisheries Series. Springer, Netherlands, pp. 315–335.

Russ, G.R., 2002. Yet another review of marine reserves as reef fishery management tools. In: Sale, P.F. (Ed.), Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem. Academic Press, Inc., San Diego, CA, pp. 421–443.

Russ, G., Alcala, A., 1996. Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. Mar. Ecol. Prog. Ser. 132, 1–9. http://dx.doi.org/10.3354/meps132001.

Russ, G.R., Alcala, A.C., 2010. Enhanced biodiversity beyond marine reserve boundaries: the cup spillith over. Ecol. Appl. 21, 241–250. http://dx.doi.org/10.1890/09-1197.1.

Sackett, D.K., Drazen, J.C., Moriwake, V.N., Kelley, C.D., Schumacher, B.D., Misa, W.F. X.E., 2014. Marine protected areas for deepwater fish populations: an evaluation of their effects in Hawai'i. Mar. Biol. 161, 411–425. http://dx.doi.org/10.1007/s00227-013-2347-9.

Sadovy, Y., 2005. Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. Fish Fish. 6, 167–185. http://dx.doi.org/10.1111/j.1467-2979.2005.00186.x.

Schug, D.M., 2001. Hawai'i's commercial fishing industry: 1820–1945. Hawaii. J. Hist. 35.

Seaton, S.L., 1974. The Hawaiian kapu abolition of 1891. Am. Ethnol. 1, 193–206. http://dx.doi.org/10.1525/ae.1974.1.1.02a00100.

Selkoe, K.A., Halpern, B.S., Ebert, C.M., Franklin, E.C., Selig, E.R., Casey, K.S., Bruno, J., Toonen, R.J., 2009. A map of human impacts to a "pristine" coral reef ecosystem, the Papahānaumokuākea Marine National Monument. Coral Reefs 28, 635–650. http://dx.doi.org/10.1007/s00338-009-0490-z.

Shanks, A.L., Grantham, B.A., Carr, M.H., 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecol. Appl. 13, 159–169. http://dx.doi.org/10.1890/1051-0761(2003) 013[0159:PDDATS]2.0.CO;2.

Shomura, R.S., 1987. Hawaii's Marine Fishery Resources: Yesterday (1900) and Today (1986). Southwest Fisheries Center, National Marine Fisheries Service, Honolulu, HI.

Shomura, R.S., 2004. A historical perspective of Hawai'i's marine resources, fisheries, and management issues over the past 100 years. In: Friedlander, A.M. (Ed.), The Status of Hawaii's Coastal Fisheries in the New Millenium. American Fisheries Society, Hawaii Chapter, Honolulu, HI, pp. 6–11.

Sladek Nowlis, J., Friedlander, A.M., 2005. Marine reserve function and design for fisheries management. In: Norse, E.A., Crowder, L.B. (Eds.), Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Island Press, Washington, DC, pp. 280–301.

Sladek Nowlis, J., Roberts, C.M., 1999. Fisheries benefits and optimal design of marine reserves. Fish. Bull. 97, 604–616.

Smith, M.K., 1993. An ecological perspective on inshore fisheries in the main Hawaiian Islands. Mar. Fish. Rev. 55, 34–49.

Stamoulis, K.A., Friedlander, A.M., 2013. A seascape approach to investigating fish spillover across a marine protected area boundary in Hawai'i. Fish. Res. 144, 2–14. http://dx.doi.org/10.1016/j.fishres.2012.09.016.

Stevenson, T.C., Tissot, B.N., 2013. Evaluating marine protected areas for managing marine resource conflict in Hawaii. Mar. Policy 39, 215–223. http://dx.doi.org/10.1016/j.marpol.2012.11.003.

Stevenson, T.C., Tissot, B.N., Dierking, J., 2011. Fisher behaviour influences catch productivity and selectivity in West Hawaii's aquarium fishery. ICES J. Mar. Sci. 68, 813–822. http://dx.doi.org/10.1093/icesjms/fsr020.

Stevenson, T.C., Tissot, B.N., Walsh, W.J., 2013. Socioeconomic consequences of fishing displacement from marine protected areas in Hawaii. Biol. Conserv. 160, 50–58. http://dx.doi.org/10.1016/j.biocon.2012.11.031.

Stewart, R.E., Desai, A., Walters, L.C., 2011. Wicked Environmental Problems: Managing Uncertainty and Conflict. Island Press, Washington, DC.

Szuster, B.W., Needham, M.D., 2010. Marine recreation at the Molokini Shoal MLCD. (Final project report for Hawaii Division of aquatic resources). Department of Geography, University of Hawaii at Manoa, Honolulu, HI.

Tanaka, W., 2008. Ho ohana aku, Ho ola aku: first steps to averting the tragedy of the commons in Hawaii's nearshore fisheries. Asian Pac. L. Pol'y J. 10, 235.

Tanaka, W.C., Miyashiro, M.A., Kaulukukui, K.L., 2012. Enforcement chain analysis of aquatic resource enforcement on Oahu Island and north shore Maui. Oahu Resource Conservation and Development Council, Honolulu, HI.

Tava, R., Keale, M.K., 1990. Niihau: The Traditions of a Hawaiian Island. Mutual Publishing Company, Honolulu, HI.

Tissot, B.N., 2005. Integral marine ecology: community-based fishery management in Hawai'i. World Futures 61, 79–95. http://dx.doi.org/10.1080/02604020590902371.

Tissot, B.N., Hallacher, L.E., 2003. Effects of aquarium collectors on coral reef fishes in Kona, Hawaii. Conserv. Biol. 17, 1759–1768.

Tissot, B.N., Walsh, W.J., Hallacher, L.E., 2004a. Evaluating effectiveness of a marine protected area network in West Hawai'i to increase productivity of an aquarium fishery. Pac. Sci. 58, 175–188.

Tissot, B.N., Walsh, W.J., Hallacher, L.E., 2004b. Evaluating the Effectiveness of a marine reserve network in West Hawaii to improve management of the aquarium fishery. NOAA Coral Reef Conservation Program, Technical Report, Honolulu, HI.

Tissot, B.N., Walsh, W.J., Hixon, M.A., 2009. Hawaiian islands marine ecosystem case study: ecosystem- and community-based management in Hawaii. Coast. Manag. 37, 255–273. http://dx.doi.org/10.1080/08920750902851096.

Toonen, R.J., Wilhelm, T.'.A., Maxwell, S.M., Wagner, D., Bowen, B.W., Sheppard, C.R. C., Taei, S.M., Teroroko, T., Moffitt, R., Gaymer, C.F., Morgan, L., Lewis, N., Sheppard, A.L.S., Parks, J., Friedlander, A.M., 2013. One size does not fit all: the emerging frontier in large-scale marine conservation. Mar. Pollut. Bull. 77, 7–10. http://dx.doi.org/10.1016/j.marpolbul.2013.10.039.

Townsend, R.E., Pooley, S.G., 1995. Corporate management of the Northwestern Hawaiian Islands lobster fishery. Ocean Coast. Manage. 28, 63–83. http://dx.doi.org/10.1016/0964-5691(95)00043-7.

Uchida, R.N., Tagami, D.T., 1984. Groundfish fisheries and research in the vicinity of seamounts in the North Pacific Ocean. Mar. Fish. Rev. 46, 1–17.

van Beukering, P., Cesar, H., 2004. Economic Analysis of Marine Managed Areas in the Main Hawaiian Islands. University of Hawaii, Honolulu, HI.

Vaughan, M.B., Vitousek, P.M., 2013. Mahele: sustaining communities through small-scale inshore fishery catch and sharing network. Pac. Sci. 67, 329–344. http://dx.doi.org/10.2984/67.3.3.

Walsh, W., 1987. Patterns of recruitment and spawning in Hawaiian reef fishes. Environ. Biol. Fish 18, 257–276. http://dx.doi.org/10.1007/BF00004879.

Walsh, W.J., Cotton, S.S., Dierking, J., Williams, I.D., 2003. The commercial marine aquarium fishery in Hawai 'i. In: Friedlander, A.M. (Ed.), Status of Hawai'i's Coastal Fisheries in the New Millennium. American Fisheries Society, Hawaii Chapter, Honolulu, HI, pp. 132–159.

Walsh, W., Cotton, S., Barnett, C., Couch, C., Preskitt, L., Tissot, B., Osada-D'Avella, K., 2013. Long-term monitoring of coral reefs of the main Hawaiian Islands (Technical report). Hawaii Division of Aquatic Resources, Honolulu, HI.

Williams, I.D., Walsh, W.J., Miyasaka, A., Friedlander, A.M., 2006. Effects of rotational closure on coral reef fishes in Waikiki-Diamond head fishery management area, Oahu, Hawaii. Mar. Ecol. Prog. Ser. 310, 139–149.

Williams, I.D., Walsh, W.J., Schroeder, R.E., Friedlander, A.M., Richards, B.L., Stamoulis, K.A., 2008. Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. Environ. Conserv. 35, 261–272. http://dx.doi.org/10.1017/S0376892908004876.

Williams, I.D., Walsh, W.J., Claisse, J.T., Tissot, B.N., Stamoulis, K.A., 2009. Impacts of a Hawaiian marine protected area network on the abundance and fishery sustainability of the yellow tang, *Zebrasoma flavescens*. Biol. Conserv. 142, 1066–1073. http://dx.doi.org/10.1016/j.biocon.2008.12.029.

Wilson, J., Yan, L., Wilson, C., 2007. The precursors of governance in the Maine lobster fishery. Proc. Natl. Acad. Sci. 104, 15212–15217. http://dx.doi.org/10.1073/pnas.0702241104.

Woodroffe, R., Ginsberg, J.R., 1998. Edge effects and the extinction of populations inside protected areas. Science 280, 2126–2128. http://dx.doi.org/10.1126/science.280.5372.2126.

Yeh, J., Drazen, J.C., 2009. Depth zonation and bathymetric trends of deep-sea megafaunal scavengers of the Hawaiian Islands. Deep-Sea Res. I Oceanogr. Res. Pap. 56, 251–266. http://dx.doi.org/10.1016/j.dsr.2008.08.005.

Zeller, D., Darcy, M., Booth, S., Lowe, M.K., Martell, S., 2008. What about recreational catch? Potential impact on stock assessment for Hawaii's bottomfish fisheries. Fish. Res. 91, 88–97. http://dx.doi.org/10.1016/j.fishres.2007.11.010.