Bottomfish Fishing in the Northwestern Hawai'ian Islands Is it Ecologically Sustainable?

October 2005

Dennis Heinemann
Hannah Gillelan
Lance Morgan

(Pearl & Hermes Atoll, NWHI courtesy of NOAA)

The Ocean Conservancy
Advocates for Wild, Healthy Oceans

MCBI
Marine Conservation Biology Institute

Bottomfish Fishing in the Northwestern Hawai'ian Islands
Is it Ecologically Sustainable?

October 2005

Dennis Heinemann[1]
Hannah Gillelan[2]
Lance Morgan[3]

SUMMARY

The Northwestern Hawai'ian Islands (NWHI) is one of the most remote and least impacted coral reef ecosystems in the world. The health of this ecosystem is very good, but not without problems. In the last century we have become aware of the plight of endangered Hawai'ian monk seals, the loss of resources such as spiny lobster, and the damage done by marine debris. Now, new information has come to light that points to further degradation of this unique ecosystem. A declaration earlier this year by the National Marine Fisheries Service (NMFS) stated that overfishing of the bottomfish stock complex–which includes over a dozen species of snappers–groupers and jacks, was occurring in 2002. NMFS ascribed the situation mostly to excessive fishing pressure in the Main Hawai'ian Islands, where the stock complex clearly is both experiencing intense overfishing and is overfished (populations sizes depleted). However, using data provided by State and Federal agencies and stock assessment criteria established recently by NMFS, it is apparent that overfishing of bottomfish has been occurring in the NWHI for a long time, and that the stock complex has been at or approaching the threshold to being overfished (depleted).

Six presidents, from Theodore Roosevelt to George W. Bush, have acted to protect the Northwestern Hawai'ian Islands. In recent years, an Executive Order, new State regulations, proposed Federal legislation, and a process to create the NWHI National Marine Sanctuary, have all sought to provide comprehensive protection of the wildlife, ecosystems and resources of the NWHI. That protection depends on reducing human impacts to negligible levels. For example, the goals and objectives of the proposed NWHI Marine Sanctuary require that human activities be compatible with maintaining the natural character and biological integrity of the ecosystem. And, the new State regulations that prohibit all commercial and recreational fishing in State waters are designed to provide "long term conservation and protection of the unique coral reef ecosystem and the related marine resources and species, and ensure their conservation and natural character for present and future generations." There can be little doubt that the human impacts that contributed to the losses of resources such as spiny lobsters and monk seals, were incompatible with the preservation and protection of the Northwestern Hawai'ian Islands, which is the primary goal of the proposed National Marine Sanctuary and what most Hawai'ians and Americans desire.

Recent research has highlighted the biological and ecological risks of fishing. For example, fishing tends to remove the largest individuals from a population. In some, perhaps most, fish these individuals may be responsible for the bulk of the population's productivity. In addition, by taking the

---

[1] Dennis Heinemann, PhD, Senior Scientist, The Ocean Conservancy, Washington DC; dheinemann@oceanconservancy.org
[2] Hannah Gillelan, Ocean Policy Analyst, Marine Conservation Biology Institute, Washington DC
[3] Lance Morgan, PhD, Chief Scientist, Marine Conservation Biology Institute, Glen Ellen CA

largest individuals, fishing is likely to result in genetic changes over time that will produce potentially permanent decreases in population productivity. Fish stocks reduced to the overfished threshold are certainly suffering a short-term and potentially long-term loss of productivity, biological integrity, and may be less resilient to other environmental stresses. Furthermore, it is quite possible that these impacts occur under much less severe fishing pressure, such as fishing rates associated with maximum sustainable or optimal yield. Finally, fishing is the only apparent factor that can explain these impacts on bottomfish.

Thus, the overfishing of the bottomfish complex in the Northwestern Hawai'ian Islands is incompatible with maintenance of natural character and the biological integrity of the ecosystem. Furthermore, consideration of the subtle biological and ecological impacts of fishing suggests that compatibility with Sanctuary goals and objectives would only occur with significantly lower fishing pressure than the target rates selected by fisheries managers. In the Northwestern Hawai'ian Islands, where only a handful of vessels have produced this situation and the fisheries management system has yet to acknowledge the problem, it is apparent that no levels of commercial fishing are likely to be compatible with the goals and objectives of the proposed Sanctuary.

INTRODUCTION

The Northwestern Hawai'ian Islands

The Northwestern Hawai'ian Islands is one of the few places on the planet where we can get some idea of what truly pristine coral-reef ecosystems must have looked like in the not too distant past. Remote, geographically extensive, possessing a large percentage of endemic species, and dominated by a large and diverse community of predators, the Northwestern Hawai'ian Islands is characterized by a unique and special ecosystem.[4] The Northwestern Hawai'ian Islands are so important and valuable to society that six presidents, from Theodore Roosevelt to George W. Bush, have acted to protect the area.

The integrity and health of the ecosystem in the Northwestern Hawai'ian Islands is perhaps as good as we can find in U.S. waters, but it is still far from truly pristine. As in other remote parts of the planet, mankind's footprints can be found even in the NWHI.

- Lost fishing gear from broad-scale fishing operations in the North Pacific creates entanglement risk for endangered wildlife and festoons the reefs in some places.[5]
- The endemic Hawai'ian monk seal (*Monachus schaunslandi*) is endangered, and is predicted to be headed for further declines from undetermined causes, which may include fishing on some of its important prey species.[6]
- Pink coral populations at the western end of the chain were heavily impacted by tangle-net dredging by the Japanese and other foreign vessels in 1970's and 1980's.[7]
- Since 1991, long-line fishing had to be banned within 50 nautical miles of the NWHI to protect monk seals, turtles and seabirds from becoming by-catch casualties.[8] However, in prior decades prior the large foreign (and then domestic) long-line fleet fishing in the

---

[4] Maragos & Gulko 2002; Friedlander *et al.* 2005
[5] Friedlander *et al.* 2005
[6] Jahanos & Baker 2004
[7] WPRFMC 2003b
[8] NMFS 1991

Northwestern Hawai'ian Islands that is documented[9] to have operated there is likely to have significantly altered populations of pelagic fishes. Given the long generation times of some of the species caught by that fishery and the ongoing fishing outside the zone, it is almost certain that the composition of the pelagic community of organisms has been altered from its original state.

- At one time, black-lipped pearl oysters were common on the Pearl and Hermes atoll, but a directed fishery mined-out this population in a very short time, and the oysters have only recently shown signs of recovery some 75 years later.[10]
- The spiny lobster fishery suffered repeated collapses and closures from extreme overfishing in the 1980's and 1990's.[11] The fishery has been closed since 2000 due to concerns about depletion, scientific uncertainty affecting the stock assessment and potential interactions with the endangered Hawai'ian monk seal.[12] The combination of severe depletion and what appears to be poor environmental conditions for recruitment apparently have prevented recovery since.[13]
- The coral reefs of the Hawai'ian Islands have recently been discovered to be part of the worldwide increase in coral bleaching that has been linked to global warming.[14]
- And now, surveys of the region are discovering for the first time introduced species in the Northwestern Hawai'ian Islands.[15]

While these impacts have negatively affected the once pristine NWHI ecosystem, it does not change the fact that–relative to other systems–this area is one of the least impacted and most intact in the world. Furthermore, with increased protection from human impacts, the NWHI could likely be restored to very near its original state.

The lack of recovery of lobster and the continued decline of monk seals highlight a well-documented vulnerability of coral-reef ecosystems to human impacts such as fishing. Numerous studies around the world have described the difficulty of achieving the sustainable exploitation of multispecies fisheries in coral-reef systems. When overfished, most of the large predators and fish are removed, which can lead to a cascade of secondary ecological changes affecting the integrity of the entire system. The Hawai'ian Islands are not immune to these problems. Recent research has demonstrated that there is a relatively large, healthy community of apex predators in the Northwestern Hawai'ian Islands that is largely absent from the Main Hawai'ian Islands.[16] The same study also found reduced abundances of lower trophic-level predators in the Main Hawai'ian Islands. These greatly depressed abundances of fishes in the Main Hawai'ian Islands are generally recognized to be largely the result of overfishing.[17]

In 1909, President Theodore Roosevelt designated the Northwestern Hawai'ian Islands a National Wildlife Refuge (NWR). The NWHI NWR still exists today and its goal is to provide for the complete protection of ecosystems, biodiversity and resources within its boundaries. For example,

---

[9] WPRFMC 1986a; WPRFMC 2003a
[10] Maragos & Gulko 2002; Friedlander *et al.* 2005
[11] Polovina & Haight 1998; WPRFMC 2003b, NOAA 2004
[12] WPRFMC 2003b
[13] Polovina & Haight 1998; DeMartini *et al.* 2003
[14] Aeby *et al.* 2003; Jokiel & Brown 2004
[15] Friedlander *et al.* 2005
[16] Friedlander & DeMartini 2002
[17] Harman & Katekaru 1988; Friedlander & DeMartini 2002

no fishing of any kind is allowed within the Refuge. In the last five years, several processes have been put in place that will greatly enhance and/or extend the protections provided the Northwestern Hawai'ian Islands.

- In 2000, President Bill Clinton issued an Executive Order establishing the Northwestern Hawai'ian Islands Coral Reef Ecosystem Reserve.[18] The Executive Order stated that: "The principal purpose of the Reserve is the long-term conservation and protection of the coral reef ecosystem and related marine resources and species of the Northwestern Hawai'ian Islands in their natural character." In addition, the Order provided that management of the area should ensure that tourist, recreational and commercial activities do: "not degrade the Reserve's resources or diminish the Reserve's natural character."
- Currently, the National Marine Sanctuary Program[19] is in the process of designating the Reserve as a National Marine Sanctuary.[20] The Goals and Objectives state that the proposed Sanctuary shall: "Protect, preserve, maintain, and…restore the natural biological communities, including habitats, populations, native species, and ecological processes,…[and] manage, minimize, or prevent negative human impacts by allowing access only for those activities that do not threaten the natural character or biological integrity of any ecosystem of the region."
- In May of this year, Representative Ed Case introduced the Northwestern Hawai'ian Islands National Marine Refuge Act of 2005 in the United States Congress.[21] The goals of the Act are: "To set aside the waters of the NWHI as a national marine refuge that fully preserves and protects in perpetuity the natural resources and cultural heritage of the area. [And:] To provide that all human activities in the Northwestern Hawai'ian Islands National Marine Refuge shall be limited to those entirely consistent with preservation and protection in the true nature of a fully protected refuge, and that all commercial use of such refuge shall be prohibited."
- And, on September 29, the State of Hawai'i established regulations creating a "no-extraction" marine refuge in the State waters of the NWHI and recommended that similar protections be enacted within Federal waters out to 50 miles around the NWHI.[22] The "intent and purpose" of refuge are to provide "long term conservation and protection of the unique coral reef ecosystem and the related marine resources and species, to ensure their conservation and natural character for present and future generations." No commercial or recreational fishing will be allowed in the refuge.

---

[18] Clinton 2000a
[19] National Ocean Service, National Oceanographic and Atmospheric Administration
[20] NOAA 2004
[21] Case 2005
[22] Office of the Governor 2005; DLNR 2005; Godvin 2005

All of these actions and proposals share a similar goal and principle – namely that the area should:

1) provide for the protection and conservation of the ecosystems and resources, and
2) preserve (i.e. not degrade, or negatively impact) the natural character, true nature or biological / ecological integrity of the area.

The Proposed NWHI National Marine Sanctuary

This approach is most clearly articulated in the goals and objectives of the proposed National Marine Sanctuary, which state that the only human activities that should be allowed in the Sanctuary are those that "do not threaten the natural character or biological integrity of any ecosystem of the region." Further, the National Marine Sanctuaries Act provides that fishing regulations must be consistent with the goals and objectives. The natural character or biological integrity criterion forms the critical basis for assessing the appropriateness of any fishing activity currently taking place or proposed for the Sanctuary.

Assessing whether any form of fishing is appropriate with respect to this criterion will require biological and ecological measures and standards of natural character, biological integrity and/or ecological integrity.[23] Fisheries science has created a whole system of measures and standards for assessing the status and condition of fisheries resources. Although those measures and standards can provide useful information in this context, they are not ideal because they are associated with a different goal, namely to maximize the sustainable yield from the system, with only a secondary consideration of the conservation of the resources. However, they are the most widely used measures and standards, and the ones used by the National Marine Fisheries Service to assess fish stocks. Thus, it is important to understand the relationship between fisheries standards and the ecological standards that would be consistent with the goals and objectives of the Sanctuary.

Assessing Fish Stocks

As required by the Sustainable Fisheries Act,[24] fish stocks in the U.S. are to be assessed with respect to their biomass (B, a measure of the abundance of the population) and the fishing mortality rate (F, a measure of the intensity of fishing), or proxies of those measures. Estimates of biomass and fishing mortality for a stock are assessed relative to reference values for the biomass and fishing mortality rate that should produce MSY (maximum sustainable yield) – B_{MSY} and F_{MSY}, respectively. B_{MSY} historically was treated as a target, but that approach has been found to be insufficiently conservative. Decades of trying to maintain stocks at B_{MSY} have shown that because of numerous ecological, social and political unknowns and uncertainties, sustainable yields can only be achieved if the biomass target takes into account these uncertainties, producing what are called 'optimal yields'; the corresponding references are OY, B_{OY} and F_{OY}.

In addition, other biomass reference values may be specified that define points at which management action is to be taken. For example, an overfished biomass threshold is often designated. Stocks dropping below this threshold are declared to be overfished, and rebuilding plans are to be put in place. Similarly, fishing mortality rates that are more conservative or establish overfishing thresholds are often defined. Each biomass level has an associated fishing mortality rate that will, in theory, produce that level. In some instances, fishing mortality rates that are completely unsustainable and will result in the crash of the population, or the stock size below which the

---

[23] The inclusion of ecological integrity comes from considering the meaning of "biological integrity of ecosystems."
[24] US Congress 1996

population will collapse due to depensatory effects, are defined.[25] The important thing to recognize is that excessive fishing will lead to significant depletion of stocks and potentially to their complete loss, and that substantially reducing fishing pressure from F_{MSY} may provide a long-term precautionary buffer to these risks.

During the development of a new fishery the biomass of the stock is reduced. In the simplest view the biomass would be reduced to B_{MSY}, where the productivity of the population is greatest and surplus productivity becomes the long-term maximum sustainable yield to the fishery. In best, precautionary practice, that reduction is managed to proceed only as far as B_{OY}, which provides somewhat less yield but much less risk of depletion.[26] However, it is important to understand that B_{OY} and B_{MSY} represent reductions in population size from the unfished state typically on the order of 40-60%, and that populations reduced to the overfished threshold may have been reduced to only 20-30% of their original size. There can be little doubt that fishing mortality rates that drive a population to the overfished threshold or beyond are incompatible with maintaining biological/ecological integrity. In fact, it is quite possible that such populations have suffered potentially permanent loss of integrity and productivity. A critical question is whether stocks at B_{MSY} or B_{OY}, or even higher levels, experience similar impacts.

The Effects of Fishing

Recent research has highlighted the effect fishing has on the age and genetic structure of populations.[27] The first and most noticeable effect of fishing is the loss of older and larger individuals in the population, which occurs because it is less likely for a fish to live to an old age (the more fishing, the more likely it is to be caught before it lives out its life), and because most fishing techniques tend to differentially take large fish over small fish. The more intense the fishing, the more extreme the loss of large individuals, or what is called age truncation. It has long been known that the loss of the largest females results in a disproportionate loss of reproductive potential because those females produce the bulk of eggs.[28] Low and moderate fishing rates have always been assumed to not seriously affect a stock's reproductive potential because, except at low population sizes, the number of eggs produced has been believed to be sufficient to replenish losses.

However, the new research is suggesting that the picture is far more complicated, and that not only do old, large females produce the most offspring, but they produce those that have the greatest chance of surviving, what is coming to be known as the BOFF (Big Old Fat Female) hypothesis. The BOFFs are responsible for the bulk of the productivity because they produce more eggs and larval fish, they provision those offspring with more nutrients, they produce offspring over a longer period of time, and those offspring grow faster and survive longer. The larger number of larval fish with greater growth/survival potential produced over a longer period time means that at least some of the BOFF offspring are more likely to encounter the right oceanographic conditions necessary for survival. Optimal conditions for survival of larval fish may not occur every year or may only occur in

---

[25] Compensation is the population response to a reduction in abundance in which the population growth rate increases. This is the response that makes a surplus available to be caught when a stock is fished down from its unfished abundance. 'Depensation' is the opposite response – population growth rate decreases in response to declines in abundance. Depensation, when it occurs, does so at very low abundances, and, therefore, increases the risk of a stock completely collapsing if fished too intensively. For example, depensation can occur if population density is so low that there are not enough males to fertilize all the eggs produced by females.

[26] 'depletion' is used in this report as a synonym of 'overfished'

[27] Birkeland & Dayton 2005

[28] Berkeley *et al.* 2004

certain areas and times during a year, which means that the longer a fish lives and the larger it is the more likely that it is going to be successful. Thus, the removal of the BOFFs, which can happen with relatively moderate fishing levels, may greatly reduce the reproductive potential of the population and lead to a greater variability in the recruitment of young fish to the population and the fishery. Although at this early stage of research into this phenomenon little is known about the effects of the loss of BOFFs, it is certain that the removal of some or most of the largest individuals and the top-down ecological control they may exert, and a greater variability in recruitment, have the potential to produce strong secondary effects within the ecosystem.

In addition to the immediate and short-term reversible effects described above, fishing also can have long-term, potentially irreversible effects that result from fishing selection. Fishing can impose a significant degree of mortality on the fished stock and typically does so differentially, preferentially taking larger fish. This differential mortality imposes a pressure on the population—selecting for fish that grow more slowly and mature earlier—producing potentially irreversible genetic changes in the population. Fishing as a selective force has been documented in the lab with controlled experiments,[29] and is the apparent cause of declines in size and age at maturity of several overfished cod stocks in the northwest Atlantic.[30] Thus, removal of the largest, most productive and important individuals may have short-term and long-term impacts on the productivity and integrity of populations, with likely ramifications for the ecosystem.

Implications

We conclude that it is quite possible that reducing populations to B_{MSY} or B_{OY}, by fishing at target rates of F_{MSY} or F_{OY}, has the potential to significantly compromise their integrity. More importantly, this damage happens with even lower levels of fishing pressure. We illustrate the relationships between the fishing mortality rate, stock biomass and the various reference points discussed previously in Figure 1. The figure tracks a hypothetical population that is fished from a pristine state all the way down to near extinction, showing the different reference points and thresholds that would be passed along the way, and the corresponding stock conditions and fishing mortality rates. We will show plots of fishing mortality versus biomass (actually proxies of these measures) in later analyses. It is important to recognize that on plots such as these stocks in the lower right-hand corner (high biomass and low fishing mortality rate) are most certainly consistent with the maintenance of natural character and ecological integrity. Conversely, stock conditions in the upper left corner (overfishing and overfished) are certainly not consistent. Where the transition from consistent to inconsistent occurs will surely depend on many factors, but we would judge that conditions in the center are likely to be inconsistent because of the significant reduction in biomass, and concomitant loss of BOFFs and imposition of fishing selection that is necessary to get a stock to the optimal or maximum sustainable yield point.

---

[29] Conover *et al.* 2005

[30] Barot *et al.* 2004; Olsen *et al.* 2004

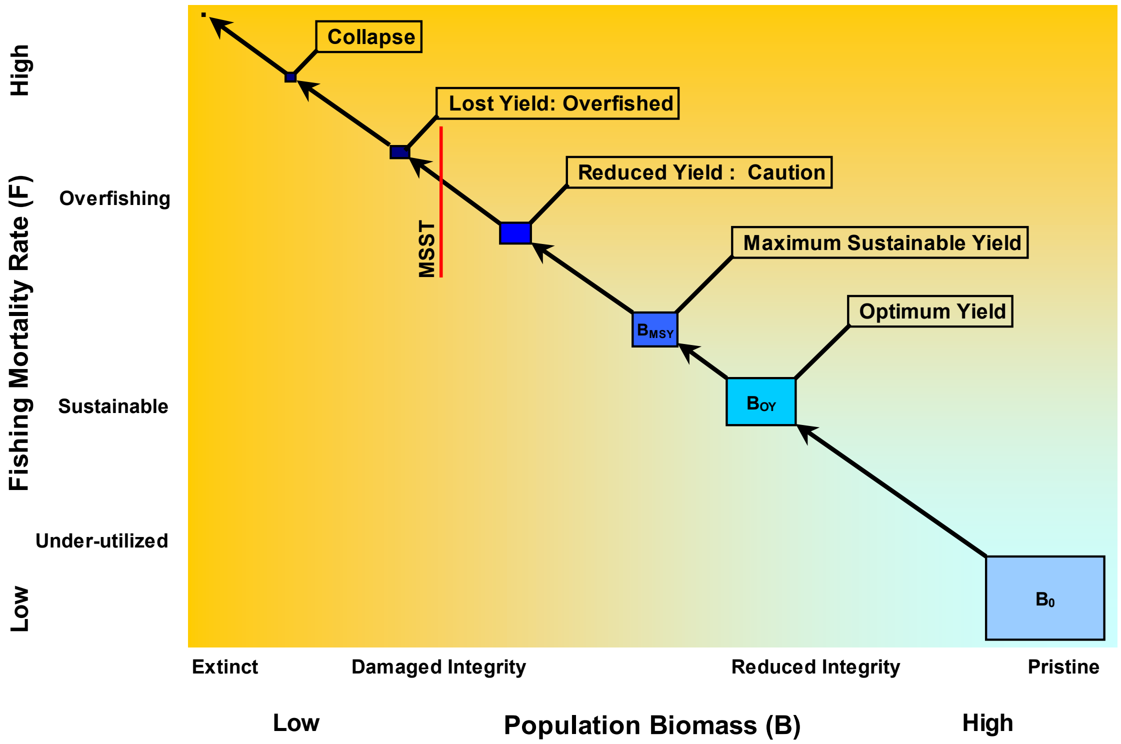

Figure 1. Hypothetical illustration of the progression of fishing, from a pristine state (B_0) to near extinction in terms of the population's biomass (size) and the fishing mortality rate (fishing pressure) that it experiences. The boxes represent the size of a population. Along the way it would pass through different population biomass levels corresponding to different management reference points, e.g. B_{OY}, B_{MSY}, the overfished threshold (usually called the Minimum Stock Size Threshold, MSST), and a possible point below which recovery is unlikely and the population collapses. Each of these biomass levels would have an associated fishing mortality rate (e.g. F_{MSY}). An actual progression would not necessarily be linear, and, of course, fisheries management actions would strive to produce the fishing mortality rate required to achieve the target biomass (e.g. B_{OY}). The background color roughly represents the decreasing biological integrity of the population that occurs as it experiences increasing fishing pressure and progresses from a pristine state (blue) to an depleted state (orange). The exact points at which reduced integrity or damaged integrity or overfishing would occur are not shown because it will depend on the biological characteristics of the population, the actual fishing mortality rates experienced and the status determination criteria established for the population.

In this paper, we will present data collected by the State of Hawai'i Department of Land and Natural Resources (DLNR) and by the National Marine Fisheries Service (NMFS) on the bottomfish fishery in the Northwestern Hawai'ian Islands. We will apply the most recent, best practice, assessment criteria established by NMFS and the Western Pacific Regional Fishery Management Council (WPRFMC) for use on this fishery, in order to describe the condition and health of bottomfish populations relative to the standards described above.

What are Bottomfish and How Are They Fished?

Bottomfish is the name given to a 'complex' of species of snappers (family Lutjanidae), groupers (family Serranidae), jacks (family Carangidae), and emperor fish (family Lethrinidae) that share a deep-water, *demersal* habit, living near the ocean floor, typically in association with underwater *headlands*, hard-bottom and high-relief habitats. Currently, 17 species are included in the complex for management purposes, called the Bottomfish Management Unit Species (BMUS).[31] However, this is only a small proportion of the number of species caught in the fishery. Most are predators, but some consume phytoplankton at the bottom of the food chain. These species occupy wide depth ranges (360-1260 feet within the limits of 0-1500 feet in depth).[32] Most fishing is concentrated between 180 and 900 feet in depth.[33] Compared to many other species most Hawai'ian bottomfish mature slowly, grow slowly, reproduce slowly and have long life spans.[34] Many species from these families form traditional spawning aggregations, predictably gathering at certain locations during certain seasons. These are characteristics that make them susceptible to overfishing[35] and less resilient to impacts. Because the fishery is managed as a complex of species, impacts can be greater on some species than on the complex as a whole. Thus, the species within the complex that are the most vulnerable to overfishing and the least resilient are of special concern.[36] One species, the hapu'upu'u (Hawai'ian grouper, *Epinephelus quernus*), is a protogynous hermaphrodite – individuals transform from female to male at about 6 years of age.[37] Because intense fishing is well known to remove older, larger individuals from the population, producing age and size truncation, overfishing can result in a sex-ratio bias (excess of females in this case) that reduces the reproductive capacity of the population.[38] This is a very real concern for this species, because in the NWHI, the fishery mostly takes hapu'upu'u that are between 10 and 30 pounds – all of which are males.[39] In addition, hapu'upu'u is an endemic species making its status of special concern. While there is a large number of bottomfish species in the Northwestern Hawai'ian Islands, more than 97% of those caught by commercial fishermen belong to just six species.[40]

Northwestern Hawai'ian Islands bottomfish fishing management is divided into two zones, the Mau Zone and the Ho'omalu Zone (Figure 2). The Mau Zone (from 161°20′W to 165°00′W) includes the waters immediately to the west of the Main Hawai'ian Islands, where Nihoa Island, Necker Island and Twin Banks are found. The remaining portion of the NWHI makes up the Ho'omalu Zone (all waters beyond the Mau Zone, i.e. west of 165°00′W).

---

[31] PIRO & WPFMC 2005
[32] DLNR 1998; WPRFMC 1986b
[33] PIFSC WPacFIN "Bottomfish Fishery" web page
[34] PIRO & WPFMC 2005
[35] Ralston *et al.* 2004
[36] Ralston *et al.* 2004
[37] Rivera *et al.* 2004
[38] Coleman *et al.* 2000; With the loss of spawning males from the population, eventually a point is reached at which there are not enough males to fertilize all the eggs produced by the females, and ultimately this trend can lead to a population decline because not enough recruits are produced to maintain the population.
[39] WPRFMC 2004
[40] The six bottomfish species that account for 97% of the catch are: ehu (red snapper; *Etelis carbunculus*), hapu'upu'u (Hawai'ian black grouper; *Epinephelus quernus*), onaga (longtailed red snapper; *Etelis coruscans*), ' pakapaka (pink snapper; *Pristipomoides filamentosus*), uku (gray snapper; *Aprion virescens*), and butaguchi (pig ulua; *Pseudocaranx dentex*) (WPRFMC 2003). Seventeen species are listed as being managed within the 'Bottomfish Management Unit' (PIRO & WPFMC 2005).

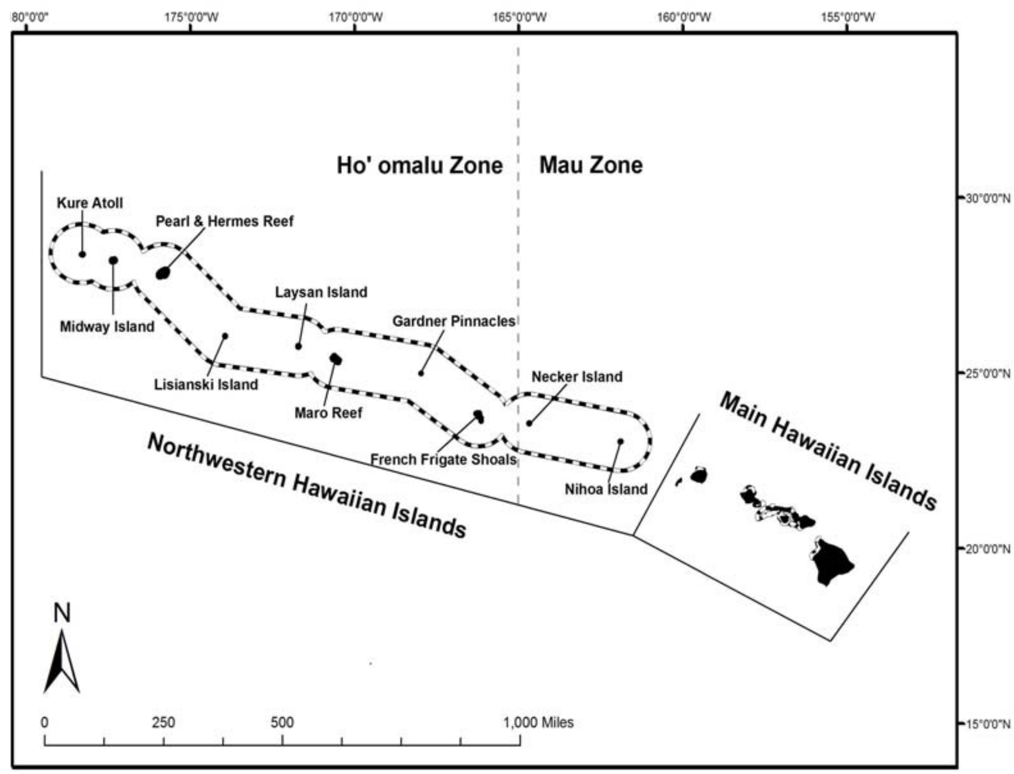

Figure 2. The Hawai'ian Archipelago showing the three bottomfish management areas, the Mau and Ho'omalu Zones of the Northwestern Hawai'ian Islands, and the Main Hawai'ian Islands.[41]

Native Hawai'ians have fished bottomfish in the Northwestern Hawai'ian Islands since the 1700's,[42] and commercial fishing has been taking place for most of the last century.[43] The bottomfish fishery in the Hawai'ian Islands is conducted primarily by medium-sized commercial fishing boats (roughly 30-45ft) that use mechanical handline gear. While hundreds of vessels participate in the Main Hawai'ian Islands, fewer than 17 vessels have operated in the NWHI in any year since 1998.[44] Commercial fishing for bottomfish in the two zones is conducted by federally-issued permit only, and the number of permits is limited. Although there are 17 valid permits (10 in the Mau Zone and 7 in the Ho'omalu Zone), in the most recent years just 5 boats a year have fished in the Mau Zone, and 4 in the Ho'omalu Zone.[45] Boats operating in the Mau Zone typically fish for bottomfish and troll for pelagic fishes. However, in the Ho'omalu Zone, almost all effort is directed toward bottomfish. Not surprisingly, most of the catch comes from the areas closest to the Main Hawai'ian Islands (62% of

[41] Map produced by J Guinotte, Marine Conservation Biology Institute
[42] WPRFMC 2003a
[43] WPRFMC 2003b
[44] PIRO & WPFMC 2005
[45] PIRO & WPFMC 2005

all catch in 2002 came from the inner third of the NWHI chain,[46] and currently none of the vessels in the fleet are operating west of Lisianski Island[47]).

The bottomfish fishery was managed under a fishery management plan (FMP) until 2000, when two Executive Orders issued by President Clinton established the NWHI Coral Reef Ecosystem Reserve and capped both the number of permits and the take of fish per permit in the fishery.[48] The multi-species complex is managed separately in the Main Hawai'ian Islands, Mau Zone and Ho'omalu Zone. Currently, the complex is assessed as a single unit within the Hawai'ian Archipelago,[49] although a panel of experts has recommended that assessment be done separately for each zone.[50] The decision to treat the complex as a single unit for assessment is based on one study showing that two snapper species show little genetic differentiation within the Archipelago, and on larval-drift simulations suggesting a degree of connectivity across the Archipelago.[51] However, a recent study of another species (hapu'upu'u) has found genetically distinct populations within the NWHI,[52] and, to date, there are no direct measurements of larval dispersal that would show whether the local populations of bottomfish are demographically connected.[53]

Fishing Patterns

Bottomfish have been fished commercially in the NWHI for at least 100 years.[54] Data on catch-per-unit-effort (CPUE, pounds per day fished) are available from 1948, and for raw landings data from 1989.[55] The landings data for the last few years show that there has been considerable fluctuation but little change in either zone: landings in 2003 were roughly the same as in 1989 (Figure 3). However, when combined (total NWHI landings), a pattern of decline is apparent since 1994. Changes in landings (catch) can be indicative of a change in stock size. However, because changes in many other factors such as the number of vessels operating in the fishery, the species being targeted, environmental factors, or market forces can produce changes in landings, no firm conclusions can be drawn. Fisheries scientists usually prefer to use catch standardized by one or more effort measures to give a useable picture of population trends.

---

[46] PIRO & WPFMC 2005
[47] Ehler 2004
[48] Clinton 2000, 2001
[49] PIFSC WPacFIN "Bottomfish Fishery" web page
[50] Ralston *et al.* 2004
[51] WPRFMC 2002a
[52] Rivera *et al.* 2004
[53] We note that genetic homogeneity does not necessarily mean that there is sufficient migration to create a single populations demographically (i.e. one that would respond to fishing and management as a single unit).
[54] PIRO & WPFMC 2005, Appendix E
[55] WPRFMC 1986b, WPRFMC 2003c, PIRO & WPFMC 2005

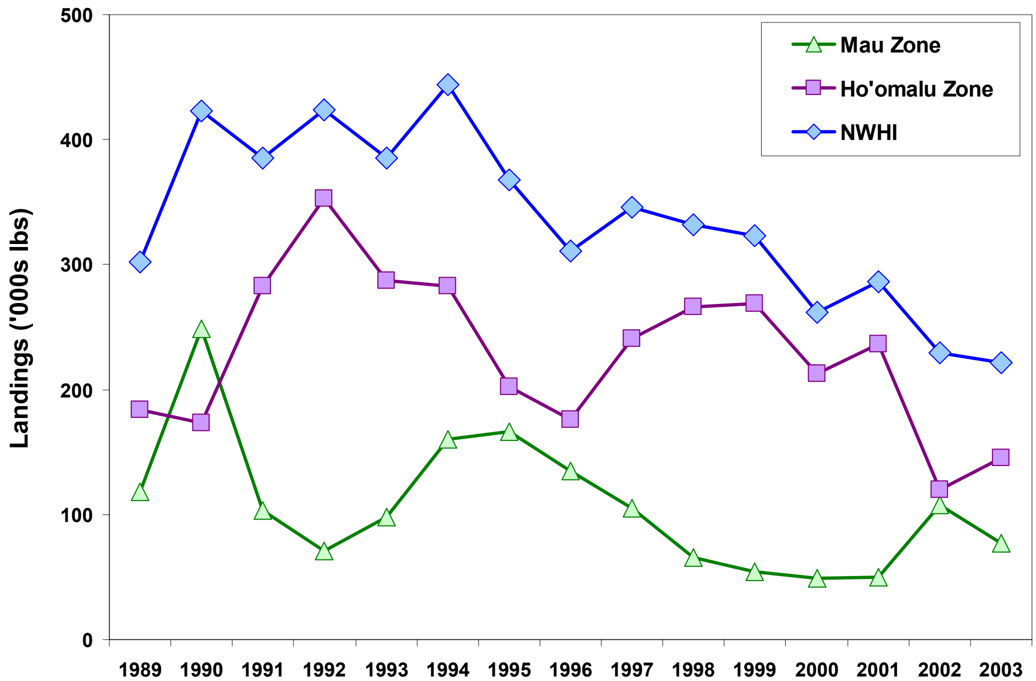

Figure 3. Landings (thousands of pounds) of bottomfish in the Mau Zone, Ho'omalu Zone and combined (NWHI) from 1989 to 2003.[56]

Corrected for the number of fishing trips that produced those landings, the data show that the catch rates of bottomfish in the NWHI have declined significantly in the last half-century. To the extent that the CPUE measure used here (pounds per trip) is a reasonable indicator of the size of the bottomfish complex, the data suggest that bottomfish biomass in the NWHI is much lower than 50 years ago. And, because the fishery was operating commercially for 50 years prior to that (with the exception of WWII), it is likely that the levels seen in 1948 were not indicative of an unfished population. In the last 10 years the catch rates in the Mau Zone have averaged less than 3,000 lbs/trip, while they were greater than that level most of the time up until 1980, averaging approximately 6,000 lbs/trip during the latter period (Figure 4).

In the more distant Ho'omalu Zone the catch rates, while varying widely year-to-year, have shown some evidence of decreasing abundance (Figure 5). From 1949 to 1964 catch rates averaged 7,152 lbs/trip,[57] varying mostly between 4,000 and 9,000 pounds per trip. From 1978 to 2003 catch-rates averaged 5,500 lbs/trip. However, there has been a significant decline in CPUE in the last 15 years (see detailed analysis below).

[56] Data from PIRO & WPFMC 2005, WPRFMC 2004

[57] Range 1535-14635 lbs/trip. Excluding the one very low value and one very high value changed the mean very little (7,009 lbs/trip).

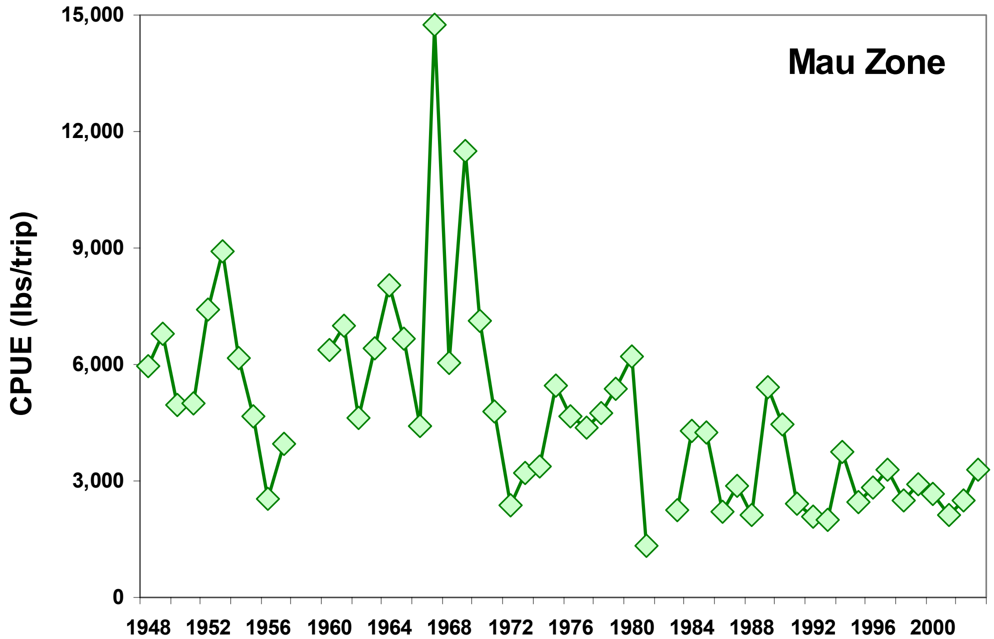

Figure 4. Catch-per-unit-effort or CPUE[58] (expressed as pounds per fishing trip in this case) of bottomfish in the Mau Zone from 1948 to 2003.[59]

---

[58] CPUE is a standard measure used in fisheries science as an indicator of the size of a population. Upon reflection, it is easy to see why annual catch alone would be a poor measure of the size of a population. Catch or landings could increase because the population size had increased, or simply because more fishermen were fishing, fishermen were putting more effort into catching fish, because they had found a way to be more effective or the wholesale price had increased. In addition, catch is a poor measure because fishermen do not 'sample' the population systematically or randomly. They go where the fish are most abundant and easiest to catch. Thus catch is typically a highly biased measure, overestimating population size and classically underestimating declines in the population. Some of these factors can be taken into account to reduce the bias. The most basic correction is to try to remove the effect of differences in effort expended. In this situation, catch is divided by (standardized by) the number of trips (one of many possible measures of effort), thus making the data from different years, in which the number of trips varied, more comparable. It is, of course, easy to see how this measure of effort could be inadequate. Imagine a situation in which effort measured in trips is not changing, but catches are declining. The catch-per-trip CPUE measure would be declining, apparently indicating a declining stock size. However, if the length of trips (and therefore the amount of time spent fishing) were decreasing, the same pattern would be produced, without a change in stock size. It is exactly this concern that has led to CPUE in catch-per-day to be used currently by NMFS (see below). A similar argument could be applied to catch-per-day (e.g. suppose there is a trend in the amount of time spent fishing per day, or the number of hooks used, or the attractiveness of the bait, etc.), and other more precise measures. In practice no CPUE measure is ever completely standardized (i.e. all sources of variation in effort and fishing power eliminated). Thus, CPUE is commonly assumed to provide a biased measure of stock size (some more biased than others). Because fishermen continually improve their fishing practices, becoming more effective with the same level of effort, it is widely recognized that CPUE routinely underestimates the rate of a stock decline. Further, bias can occur when there are opportunities to sequential fish down differ areas and different stocks within a stock complex, as is the case in the NWHI (Ralston *et al.* 2004).

[59] Data points are open diamonds connected to show the changes from year to year; gaps in the series are due to missing data for some years; data from PIRO & WPFMC 2005, WPRFMC 2004.

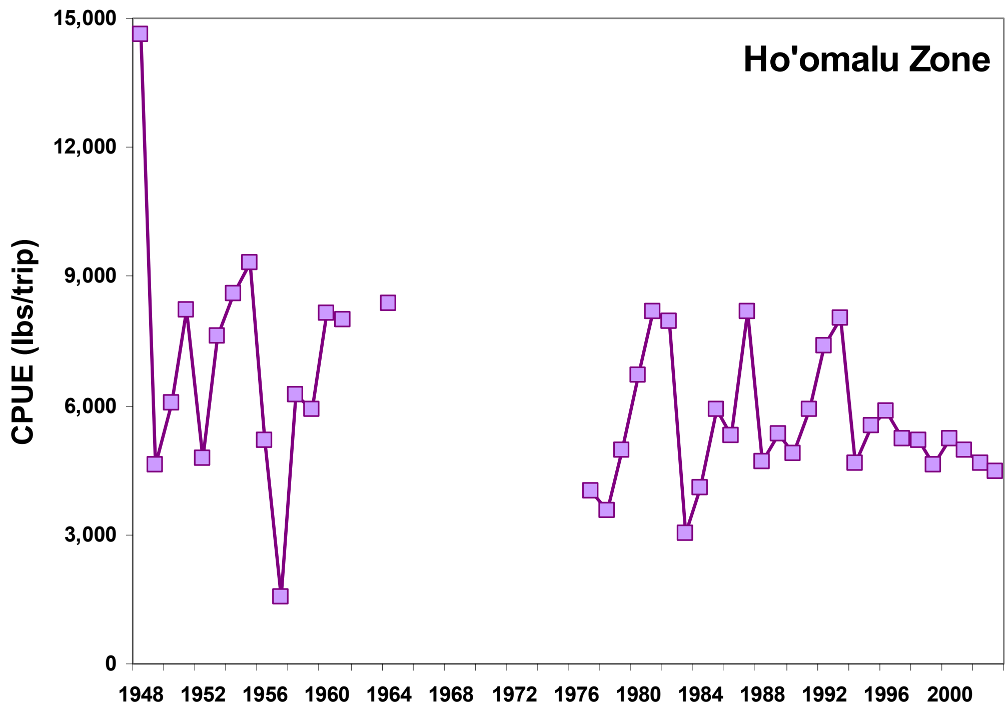

Figure 5. Catch-per-unit-effort (pounds per fishing trip) of bottomfish in the Ho'omalu Zone from 1948 to 2003.[60]

Until very recently, the WPFMC and NMFS have assessed the status and health of the bottomfish stock assemblage using a measure called the dynamic spawning potential ratio (SPR).[61] Dynamic SPR is a measure of a stock's reproductive potential relative to that of its maximum and reflects the cumulative effect of fishing mortality. When SPR is used in the assessment of fisheries stocks fisheries managers, with the advice of scientists, select SPR reference levels as limits, assessing stocks as overfished when they cross those limits. In the case of the Hawai'ian bottomfish fishery, if the stock complex has an SPR < 20% it would be declared to be recruitment overfished.[62] By implication, stocks with SPRs > 20% are considered not overfished. However, it is more realistic to consider stocks with SPRs near the limit–where "near" varies depending on the biology of the

[60] Data points are open squares connected to show the changes from year to year; gaps in the series are due to missing data for some years; data from PIRO & WPFMC 2005, WPRFMC 2004.

[61] Dynamic SPR is defined as the ratio between the average spawning potential (usually number of eggs produced) of a recruit in the current population to the same measure for an unfished population and combines information on biomass and fecundity. Fish grow continuously throughout their lives and so continually get larger as they get older, which means that they produce more and more eggs as they age. Age/size truncation in response to fishing means that the mean reproductive potential of the population declines as fishing becomes more intense and removes more and more older fish. Eventually so many spawning-age fish can be removed that the reproductive output of the population becomes insufficient to maintain the population, a process called recruitment overfishing. SPR provides a measure of this process.

[62] WPRFMC 1990

species–to be heavily impacted and threatened by excessive fishing. Ideally, fisheries management should target reference levels that are well short of such limits to create a precautionary buffer. While such buffers have been used for sensitive species in many other regions, the WPFMC has continued to use a no-buffer threshold of 20% in this fishery.

In general, SPR estimates for species in the NWHI have remained above 20% as far back as the data are available, leading managers to conclude that the complex was being fished in a sustainable fashion. In the Mau Zone average SPR values have ranged from 35 to 70% since the mid-80s. In the Ho'omalu Zone SPRs have generally been somewhat higher, but there is evidence of decline, perhaps indicating that fishing pressure was increasing or excessive (see below).

However, SPR does not provide a direct estimate of stock status or fishing mortality rate. In addition, recent work has shown that much higher SPR thresholds (30-60%) should be used to be precautionary and have a reasonable chance of developing long-term sustainability, and that the lower a species' resilience to depletion the higher the threshold should be.[63] Finally, the Magnuson-Stevens Act and its National Standard 1 Guideline require that stocks be assessed explicitly in terms of separate measures of biomass and fishing mortality rates (or their proxies), to determine overfished status (biomass or population size) and overfishing status (fishing pressure on the population).[64]

Table 1. Bottomfish multispecies complex assessment reference values for the Mau and Ho'omalu Zones of the NWHI.[65]

Area	MSY (lbs/yr)	CPUE at MSY (lbs/day)	Effort at MSY (days/yr)
Mau Zone	97,904	470	208
Ho'omalu Zone	339,728	431	789

As a result, NMFS rejected the use of SPR in this fishery,[66] and has established status determination criteria consisting of assessment reference values and a control rule to determine when stocks are overfished and subject to overfishing.[67] Because direct measures of biomass and fishing mortality are not available for the bottomfish fishery, proxies of the measures were chosen.[68] In addition, because estimates or proxies are not available for individual species within the bottomfish species

[63] Restrepo *et al.* 1998

[64] WPRFMC 2002a

[65] Data from WPRFMC 2004. These values are the best estimates made by NMFS of the Maximum Sustainable Yield in pounds per year that can be removed from the bottomfish stock complex in each zone, and the CPUE (catch-per-unit-effort, in average lbs/day) and Effort (days/year) that will produce MSY when the complex is at B_{MSY}. The MSY estimates were derived from production-model MSY estimates for the complex in the Main Hawai'ian Islands (Polovina & Moffitt 1980) expressed on per-area basis, and extrapolated to the estimated available habitat in the NWHI (WPRFMC 1986a).

[66] Ralston *et al.* 2004

[67] Status determination criteria are defined in National Standard Guideline 1 (50 CFR 600.310) to the Magnuson-Stevens Act to consist of criteria to measure the biomass of a stock and the fishing mortality imposed on that stock relative to reference values for MSY, the biomass at MSY (B_{MSY}) and the fishing mortality rate at MSY (F_{MSY}), or proxies for those measures. In addition, the criteria include a control rule that specifies the relationship between biomass and fishing mortality criteria, and graphically shows the overfishing/overfished status of stocks.

[68] Moffitt & Kobayashi 2000; Ralston *et al.* 2004; proxies are routinely used in fisheries management when direct, accurate and reliable measures of biomass and fishing mortality are not available.

complex in the NWHI, reference values for the proxies were established for the complex as a whole. As a proxy for biomass, catch-per-unit-effort (CPUE), measured as pounds landed per day fished was chosen,[69] and effort as total days fished was chosen as the proxy for fishing mortality. Estimates of the maximum sustainable yield (MSY) for the fishery were established, along with the corresponding estimates for CPUE at MSY and Effort at MSY (Table 1).[70]

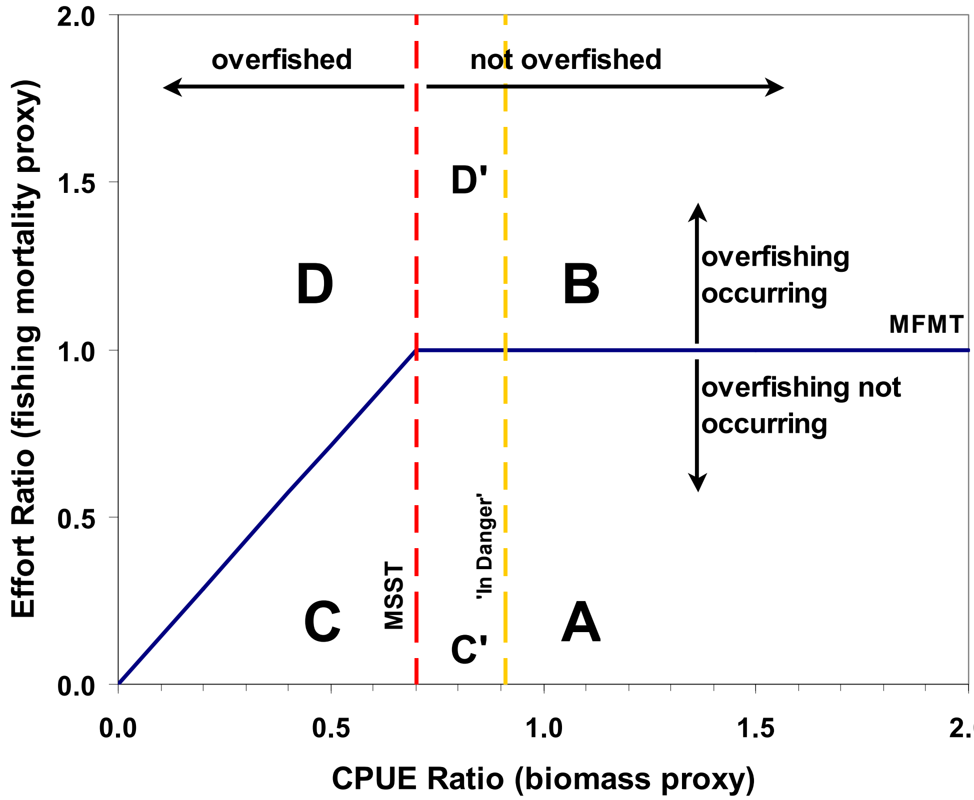

Figure 6. General form of the control rule selected for management and assessment of the bottomfish species complex in the Hawai'ian Islands Archipelago. The lines defining the Maximum Fishing Mortality Threshold (MFMT; solid blue) and the Minimum Stock Size Threshold (MSST; dashed red) are used to indicate whether a stock is overfished and/or experiencing overfishing, respectively.[71] The dashed yellow line defines a threshold, below which, but above MSST, a stock is considered in danger of being overfished.

[69] Standardizing catch by days fished is preferable to trips (used earlier) because trips can vary widely in length. For example, from 1989 to 1996 the average number of days spend fishing on trips in the Mau Zone was 5.7 days, and 10.9 days in the Ho'omalu Zone. From 1997 to 2001 the averages were 4.4 and 10.4 days, respectively.

[70] These are proxies for B_{MSY} and F_{MSY}.

[71] The control rule is used in the following manner. First, one or more joint values for the CPUE and Effort Ratios are plotted on the graph; each joint value would represent the state of the complex (biomass proxy) and fishery (fishing mortality proxy) in a given year. The graphical form of the rule then shows that values below the blue line (MFMT) represent stocks that are not being overfished, while those above the line are being overfished (too much fishing effort to sustain the desired biomass). Values to the left of the dashed red line (MSST) indicate that stocks are overfished, and values to the right indicate stocks are not overfished. Values in between the MSST line and the yellow dashed line indicate stocks are in danger of

The control rule chosen for the bottomfish fishery defines the relationship between the biomass proxy (CPUE) and the fishing mortality proxy (Effort), and the thresholds defining overfishing and an overfished state. The control rule can be described in words, with mathematical formulae, or displayed graphically (Figure 6).

First, the rule displays the determination criterion that states that the complex is assessed to be overfished if the current CPUE estimate is less than 70% of the CPUE at MSY reference value (i.e. the CPUE ratio is less than 0.7); this limit to biomass is called the Minimum Stock Size Threshold (MSST). In addition, a "yellow-light" biomass determination criterion was established: CPUE ratio estimates that fall below 0.91 (CPUEs 91% - 70% of CPUE at MSY) are taken to indicate that the complex is in danger of being overfished. Second, the rule defines the fishing mortality criterion, which states that overfishing is occurs when the Effort Ratio exceeds 1.0 (i.e. when the Effort for the current year exceeds the reference value for Effort at MSY), if the biomass estimate is not below the reference value for CPUE at MSY; this reference value is called the Maximum Fishing Mortality Threshold (MFMT). If the current CPUE is less that the reference value, then the acceptable Effort declines proportionately (the sloping portion of the MFMT line).

Table 2. Bottomfish multispecies complex status in 2002.[72] CPUE-ratio and Effort-ratio data for the Archipelago, and the MHI, Mau Zone and Ho'omalu Zone individually.

Area	CPUE Ratio	Effort Ratio
Hawai'i	0.72 – 0.86	1.14 – 1.35
MHI	0.44 – 0.75	1.86 – 2.33
Mau Zone	0.93	1.19
Ho'omalu Zone	0.96	0.37

The 2003 Bottomfish Annual Report applied this control rule to the data for the Hawai'ian Islands from 2002 (Table 2, Figure 7). Two important facts about the status of bottomfish in 2002 in the NWHI are apparent from Figure 7. First, overfishing was occurring in the Mau Zone in 2002 (Effort Ratio = 1.19, which is greater than the overfishing threshold – the MFMT line). Second, the CPUE Ratios for both zones were very close to the cautionary threshold (the dashed yellow line), indicating that the complexes there were very near to being in danger of being overfished. Given the inherent uncertainty in such measures it is only prudent to treat the stock complex as in danger.

being overfished. The graph can be divided into four quadrants representing regions of CPUE – Effort values that correspond to conditions in which A) the complex is not overfished and not experiencing overfishing, B) the complex is not overfished but is experiencing overfishing, C) not overfished but experiencing overfishing, and D) overfished and experiencing overfishing; two other regions are: C' – in danger of being overfished but not experiencing overfishing, and D' - in danger of being overfished and experiencing overfishing. Thus, stocks are in the best condition and least threatened in quadrant A, and in the worst condition and most threatened in quadrant D. The axes in this graph are effectively the same as those in Figure 1. The lower right corner of quadrant A corresponds to near pristine, under-utilized situations and quadrant D to overfishing/threatened stocks experiencing overfishing .

[72] This table contains some of the data presented in Table 3 of Appendix 5 of the 2003 bottomfish annual report (WPRFMC 2004); omitted are data from other areas.

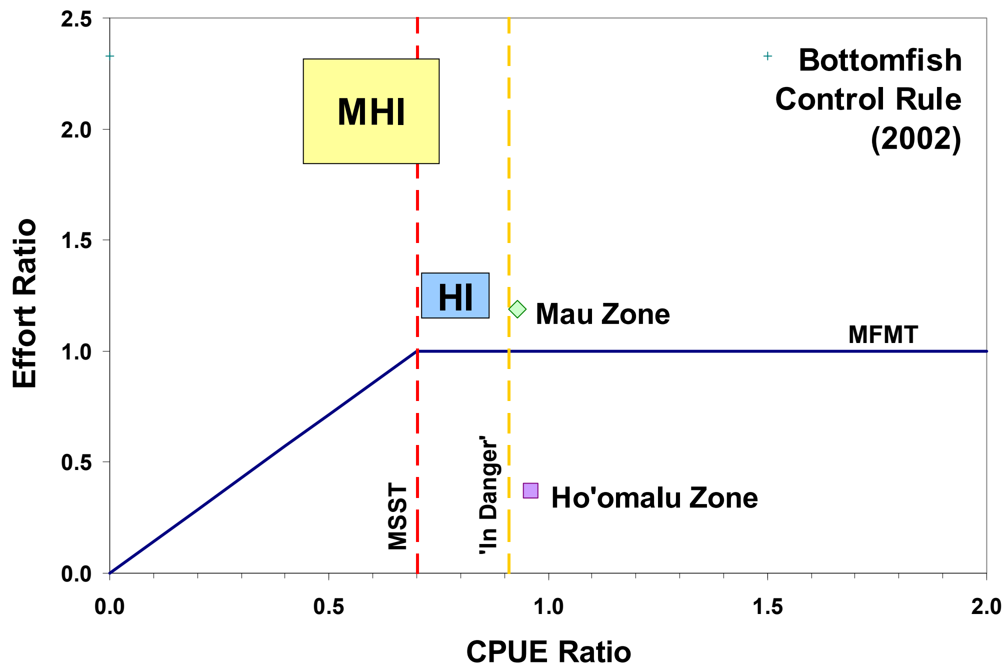

Figure 7. Control rule applied to data for the bottomfish species complex in the Hawai'ian Islands Archipelago from 2002.[73] Data are shown for the Hawai'ian Islands as a whole (yellow box labeled 'HI'), for the Main Hawai'ian Islands (blue box labeled 'MHI'), the Mau Zone (green diamond), and the Ho'omalu Zone (purple square).

Applying this status determination methodology to the past 16 years of data (1988-2003), it is clear that fishing for bottomfish in the NWHI is not sustainable, has resulted in the depletion of the complex in the Mau Zone, and is driving the complex toward depletion in the Ho'omalu Zone.

[73] This figure is a partial replicate of Figure 1 in Appendix 5 of the 2003 bottomfish annual report (WPRFMC 2004); it leaves out data on areas other than the Hawai'ian Islands and provides more explicit labeling of the elements of the control rule.

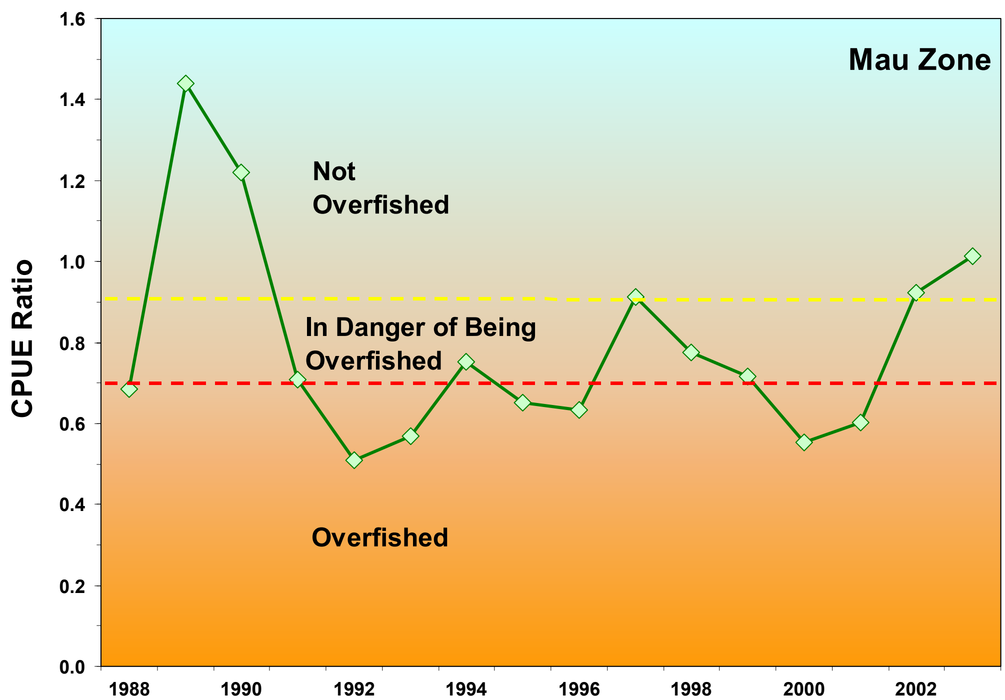

Figure 8. Bottomfish complex CPUE estimates (the biomass proxy) in the Mau Zone from 1988 to 2003.[74] The 'Not Overfished', 'In Danger of Being Overfished' and 'Overfished' regions are shown as status references.[75]

In the Mau Zone, CPUE estimates indicate that the bottomfish complex has been in an overfished state for 7 of 16 years, and in or very close to the danger zone for another 6 years (Figure 8); the index has indicated an undepleted complex only from 1989 – 1990 and in 2003. It appears that biomass has been increasing since 1992, although with large swings up and down it is difficult to know how strong this trend is. Because these measures are based on the activities of a very small number of boats, no one value can be considered to be a fully reliable indication of the status of the complex. However, considering the entire time period, these estimates provide compelling evidence that the bottomfish complex in the Mau Zone has been at or near (slightly above and below) the overfished threshold for most of the last 16 years.

Although the Ho'omalu Zone has been continually above the "in danger" region, and overfishing has not been occurring there (data not presented), there has been a steady decline in the bottomfish complex, from 2 times the MSY reference value in 1988 to just above the in danger threshold in the most recent years (Figure 9). Projecting the decline in the Ho'omalu Zone CPUE Ratio beyond 2002 suggests that, if the same average rate of decline continues, then the complex could pass into the danger zone by 2006 and into an overfished state by 2010.

[74] Data for 1988 to 2002 obtained from PIRO & WPFMC 2005; data for 2003 obtained from the Pacific Islands Fisheries Science Center, NMFS, Honolulu, Hawai'i (Gerard Dinardo and Robert Moffitt, pers. comm.).

[75] The dashed yellow and red lines are the "in danger of being overfished" and "overfished" thresholds.

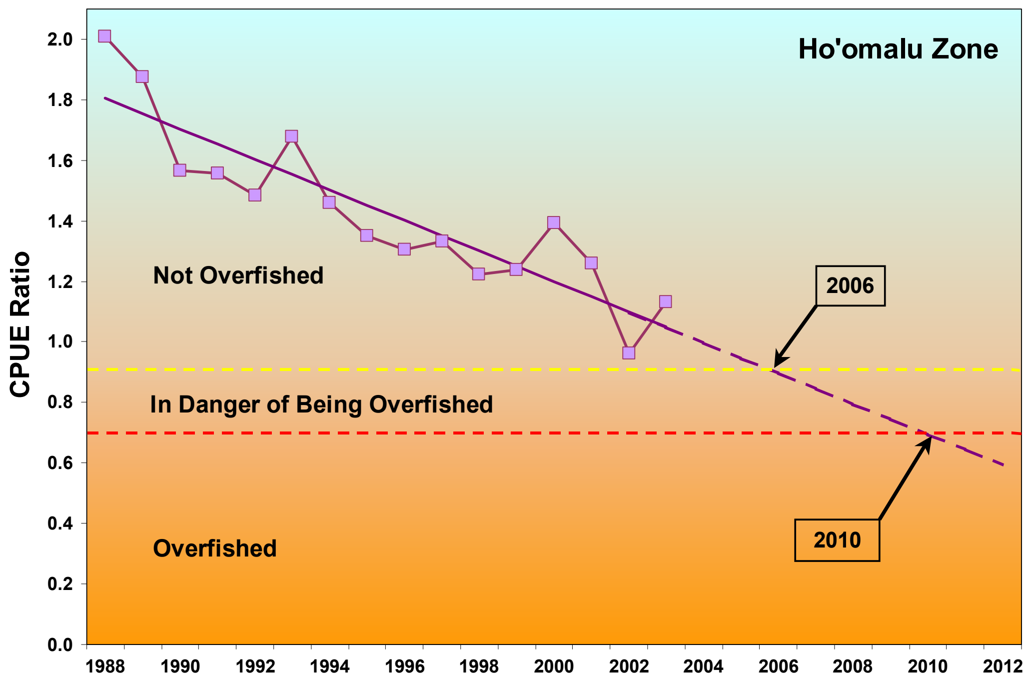

Figure 9. Bottomfish complex CPUE estimates (biomass proxy) in the Ho'omalu Zone from 1988 to 2003.[76] The "Not Overfished," "In Danger of Being Overfished" and "Overfished" regions are shown as status references.[77] A linear trend line was fit to the data (R^2=80%) and extrapolated to 2012 to give an indication of when the complex would enter into the In Danger of Being Overfished and the Overfished regions, assuming that the trend continues as it has so far.

While application of the control rule to data from 2002 showed that overfishing was occurring in the Mau Zone, as described earlier, the just released data from 2003 fell just below the threshold. Therefore, it is important to know if 2002 was an anomaly or part of a persistent pattern. Applying the control rule to data going back to 1989, it is apparent that the Mau Zone was experiencing intense overfishing from 1990 to 1996 (Figure 10). During this period of intense overfishing – effort exceeded the overfishing threshold (MFMT) by 43-161%. In recent years, 1997 to 2002, effort has oscillated around the overfishing threshold.

[76] Data sources same as in previous figure.
[77] The dashed yellow and red lines are the 'in danger of being overfished' and 'overfished' thresholds.

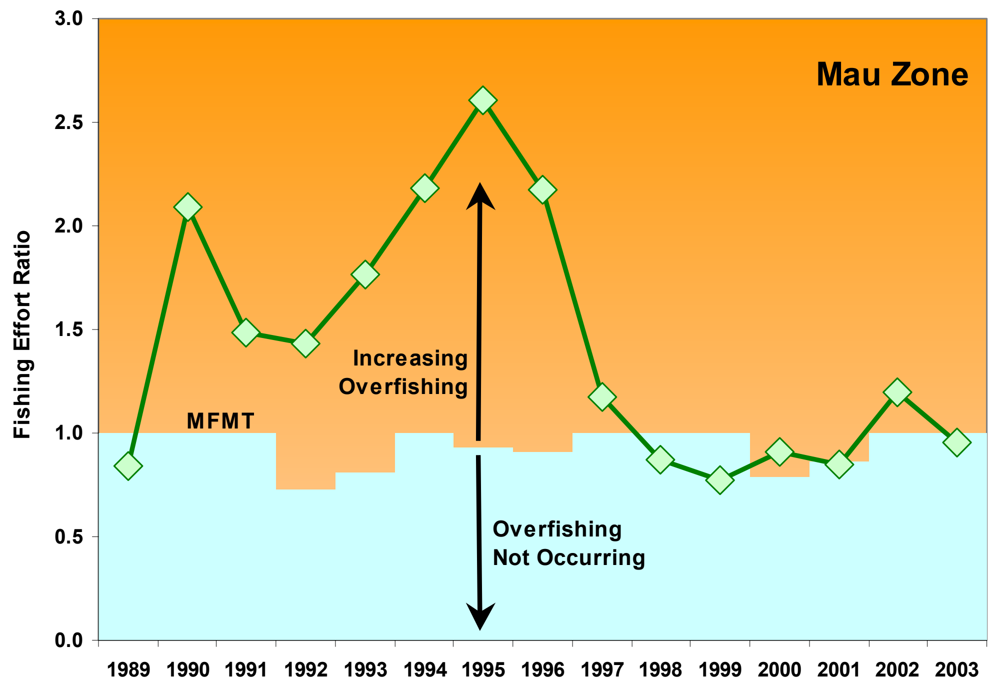

Figure 10. Fishing Effort Ratio (proxy for current fishing mortality rate relative to the reference value) in Mau Zone from 1989 to 2003.[78] Overfishing was occurring in the orange region of the graph and not occurring in the blue region; the boundary between the two is the MFMT (Maximum Fishing Mortality Rate) from the Control Rule.[79]

The assessment of fishing pressure and stock-complex status in the Mau Zone (Figure 8 and Figure 10), can be viewed together in a phase-plot, which shows the time series of effort-CPUE values overlain on the control rule (Figure 11). This view of the data provides a clearer, more comprehensive illustration that the status of the fishery has generally declined since 1989, and that it is an undesirable region with respect to biological and ecological criteria. Although the stock complex was close to the fisheries management target in 2003, this figure shows how far the complex has been away from a status consistent with the ecological standards applied by the Sanctuary (the lower right-hand corner of the plot).

[78] Data sources same as for previous two figures.

[79] The overfishing threshold (MFMT) is not constant. It varies depending on the biomass of the complex. As CPUE decreases below the overfished threshold, MSST, the overfishing threshold (MFMT) decreases proportionately (see Figure 6 or Figure 7).

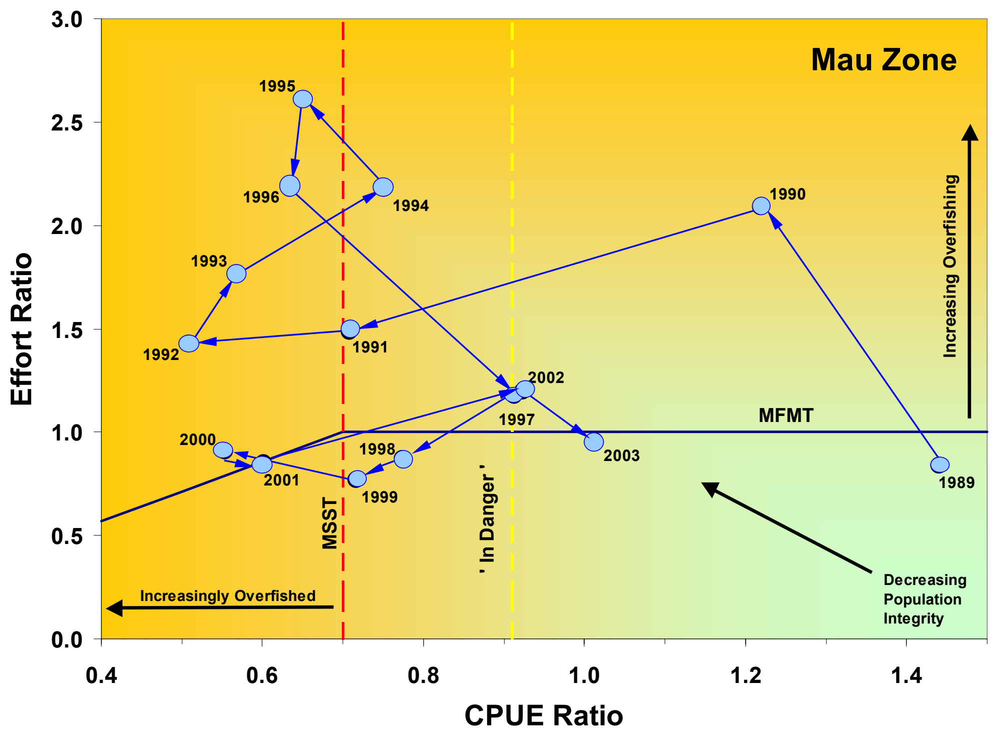

Figure 11. Phase plot showing the trajectory of the bottomfish complex in the Mau Zone in terms of the biomass proxy (CPUE Ratio) and fishing mortality proxy (Effort Ratio) from 1989 to 2003 (i.e. overlain on the Control Rule).[80]

To recap, the data and assessment methodology provided by NMFS and the WPFMC allow the determination of the status of the bottomfish complex in the NWHI. Three patterns of particular concern emerge from the assessment.

1. **Overfishing in Mau Zone from 1990 to 1996 (Figure 10).** Fishing pressure in the Mau Zone was intense prior to 1997. Although much lower recently, fishing effort is still very close to the overfishing threshold.
2. **Bottomfish overfished in the Mau Zone (Figure 8).** Bottomfish stocks in the Mau Zone have hovered around the overfished threshold since 1991, falling below the threshold in 6 of 13 years. There is some indication of a gradual, although erratic, improvement from 1992 on.
3. **Bottomfish approaching overfished condition in Ho'omalu Zone (Figure 9).** The biomass of the bottomfish complex, as indicated by catch-per-unit-effort (CPUE), in the Ho'omalu Zone has been declining steadily since the best CPUE data were first collected in 1988. At the average rate of decline the complex is expected to be in danger of being overfished by 2006 and overfished by 2010.

[80] See Figure 8 and Figure 10 for description of the elements of the Control Rule; data sources the same as in the previous three figures.

These patterns are of a concern because they show that 1) bottomfish fishing in the NWHI is not ecologically sustainable, 2) the complex is in a depleted state, near depleted state, or headed in that direction, 3) the intensity of fishing and stock depletion is almost certainly having short- and long-term impacts on the integrity of the bottomfish populations, and, 4) therefore, bottomfish fishing is not compatible with protecting and preserving the NWHI ecosystem's integrity and health, as required by the proposed NWHI National Marine Sanctuary.

Recent publications by the WPFMC and NMFS suggest that the agencies are unaware of these problems, ignoring the implications of the data, and/or unwilling to deal with them.[81] On June 14, 2005 NMFS published a notice in the Federal Register declaring that "overfishing is occurring on the bottomfish multi-species stock complex (bottomfish complex) around the Hawai'ian Archipelago," based on the data from 2002.[82] A letter from the Secretary of Commerce to the WPFMC referenced data presented in the 2003 annual bottomfish report,[83] and stated that "…the main Hawai'ian islands (MHI) is where the overfishing problem primarily occurs. MHI is the zone that contributes most of the problems in terms of both reduced biomass and overfishing. Therefore, it is likely that reducing fishing mortality here would be the most effective means to end overfishing in the Hawai'ian Archipelago."

However, the data from that report, which were presented earlier (Table 2, Figure 7), clearly show that overfishing was also occurring in the Mau Zone, and that bottomfish in both zones were very close to the "in danger of being overfished" threshold. While the fishing pressure in the Main Hawai'ian Islands and the conditions of the complex there are undeniably much worse than in the NWHI (see Figure 7, which shows that fishing effort in the MHI was 1.9-2.3 times too high in 2002, and that the complex is clearly overfished, 44-75% of the reference value), the same data and determination criteria show that there has been a history of problems in the NWHI. Unfortunately, the WPFMC and NMFS have yet to acknowledge the problems in the NWHI, continue to state that current fishing levels are sustainable and that stocks are not overfished, and have even proposed to increase the level of fishing.[84]

In the absence of clear evidence that reducing fishing pressure in the Main Hawai'ian Islands will result in a recovery of the stocks there and lead to a replenishment of the stocks in the Northwestern Hawai'ian Islands, overfishing should be addressed in the NWHI. However, this will not be done until the WPFMC and NMFS first acknowledge the problem, follow the guidelines of the Magnuson-Stevens Act to eliminate overfishing and rebuild overfished stocks, and acknowledge the requirement to propose fisheries management approaches that are consistent with the Sanctuary Goals and Objectives.

OTHER REASONS FOR CONCERN

Catches Exceeding MSY

While the Fishery Management Plan[85] for bottomfish does not include any restrictions on the amount of bottomfish taken in the fishery, the Executive Orders establishing the NWHI Coral Reef

---

[81] e.g. "Bottomfish resources in the NWHI remain relatively healthy." (WPRFMC 2004); "Currently, bottomfish resources in the NWHI are classified as healthy, and well above overfished thresholds." (PIRO & WPFMC 2004)

[82] NMFS 2005

[83] WPRFMC 2004

[84] WPRFMC 2005a,b

[85] WPRFMC 1986a, and amendments

Ecosystem Reserve restrict "the annual aggregate level for each permitted bottomfisher … [to] that permittee's individual average taken over the 5 years preceding December 4, 2000."[86] The Fisheries Management Council has never calculated this for each permit holder, but the average of all the permit holders during the 5 years preceding December 4, 2000 was 81,000 pounds in the Mau Zone and 233,000 in the Ho'omalu Zone.[87]

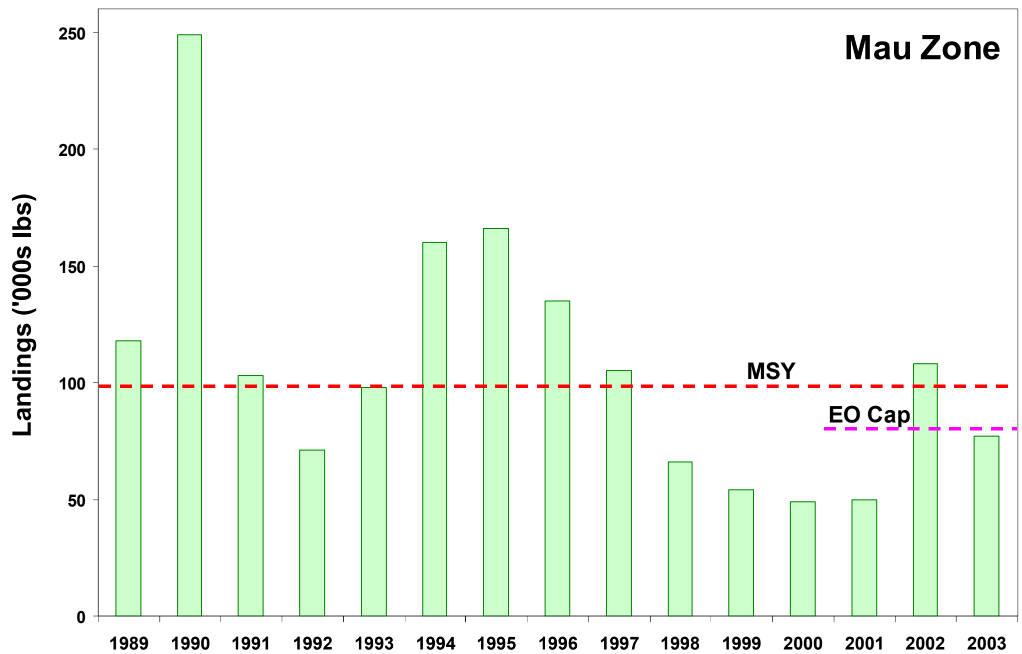

Figure 12. Bottomfish landings (thousands of pounds) in the Mau Zone from 1989 to 2003, with MSY (Maximum Sustainable Yield; dashed red line) and the EO-Cap (dashed magenta line) levels shown as references.[88]

In addition, NMFS has recently established reference MSY values for bottomfish in the Mau and Ho'omalu Zones (Table 1). Under the guidelines provided by NMFS,[89] MSY is meant to be a limit or ceiling on catch (yield) not to be exceeded. However, actual catch has exceeded MSY in 9 of the 15 years between 1988 and 2002 in the Mau Zone (Figure 12), and in 1 of these years in the Ho'omalu Zone (Figure 13). In the years in which MSY was exceeded in the Mau Zone, it was exceeded by an average of 41% and as much as 154%. The Executive Order caps were exceeded by 27,000 pounds (33%) in 2002 in the Mau Zone, and by 3,000 pounds (1%) in 2001 in the Ho'omalu Zone, apparently without any response by the Government.

[86] Clinton 2001
[87] Data from the bottomfish fishery annual reports written by the WPRFMC
[88] Data from PIRO & WPFMC 2005, WPRFMC 2004
[89] Restrepo et al. 1998

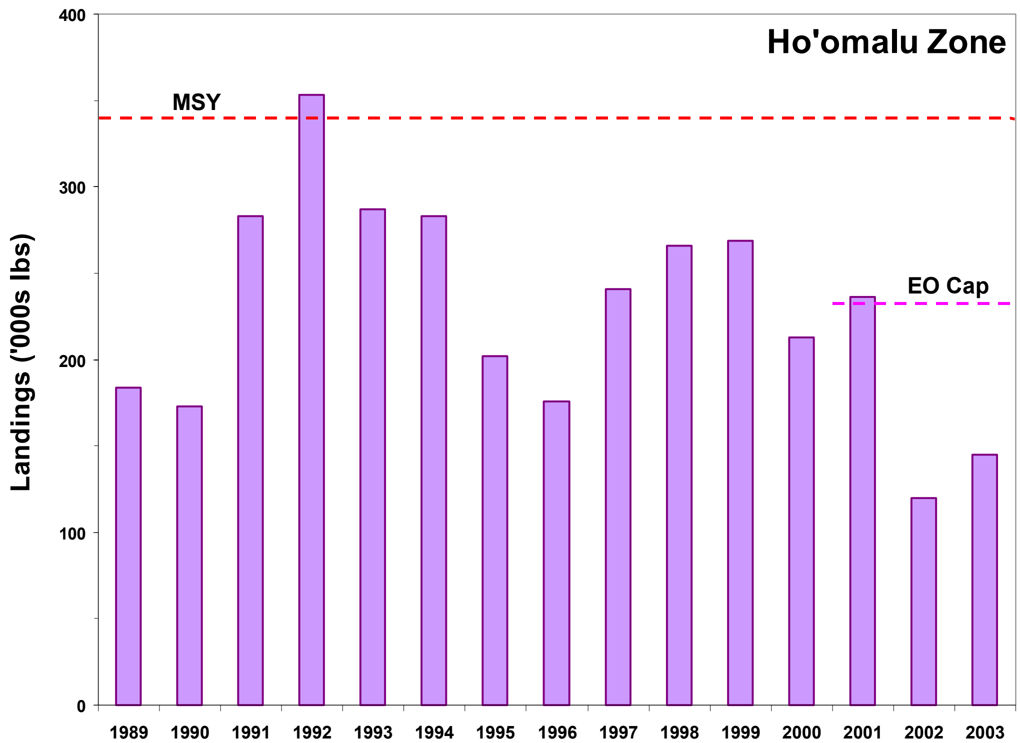

Figure 13. Bottomfish landings (pounds) in the Ho'omalu Zone from 1989 to 2003, with MSY (Maximum Sustainable Yield; dashed red line) and the EO-Cap (dashed magenta line) levels shown as references.[90]

Because bycatch is not included in the landings statistics, the removal of bottomfish from the NWHI is certainly greater than is indicated from these data. Fish that are caught may be kept for sale, kept for personal use, released or discarded for economic or regulatory reasons.[91] The latter two categories would not appear in the landings data and only catch kept for sale would appear in the landings data. The term bycatch refers, in this context, to catch kept for personal use or discarded, but not released alive. Other sources of mortality, of poorly known magnitude, are from fish that escape after being hooked and subsequently die or are eaten by predators, and from predators taking hooked fish.[92] A rough estimate from NMFS fisheries observers suggested that approximately 25% more fish were lost to predators as were landed. NMFS has summarized the bycatch situation as: "Bycatch rates are low in the bottomfish fisheries, but poor correspondence among observer, logbook, and experimental fishing data indicate a level of uncertainty associated with bycatch estimates for the NWHI fishery."[93] Data indicate that bycatch of target species is usually low, but

[90] Data from PIRO & WPFMC 2005, WPRFMC 2004
[91] PIRO & WPFMC 2005
[92] PIRO 2004
[93] PIRO 2004

can be up to 100% of non-target species,[94] suggesting that fishing pressure on some species may be much higher than realized and, therefore, these limits may have been exceeded more often than indicated in Figure 12 and Figure 13.

Other Declining Biological Reference Values

A recent WPFMC document states that: “Based on SPR values, bottomfish resources in the NWHI remain relatively healthy” and “Analysis of SPR and percent immature in the catch show no localized depletion problems to date for any [bottomfish] species in either zone of the NWHI.”[95] SPR is no longer used as the basis for assessment of the bottomfish complex, but SPR, and other measures such as the mean size of fish and percent immature fish in the catch, can still be used to provide additional information on the condition of the stocks. However, the Council’s statement is not completely supported by the data. Each of these biological reference measures shows signs of a continuing impact on some species with the complex. During the history of a fishery that is being depleted it is expected that changes will occur in certain biological reference measures. As described above, SPR is an explicit measure of the depletion process. Because the largest fish are removed preferentially, changes in the mean lengths of fish in the catch will occur over time. And, because the largest fish are the oldest, it is expected that the percentage of immature fish in the catch will increase over time (i.e. as there are fewer larger, older, mature fish in the population to catch).

Mau Zone SPR estimates for onaga closely track the CPUE ratio estimates for that region (Figure 14), showing that changes in NMFS biomass assessment measure are mirrored by SPR. Although, there was not a strong trend in CPUE in the 1988-2002 data, we know from earlier analyses that the estimates indicate that the complex was below or near the overfished threshold for most of the period. As well, the SPR values in the last few years have been repeatedly at or below 30%, which is the current minimum recommended level in fisheries science for resilient species.[96] The life-history characteristics of the bottomfish species means that they are not particularly resilient to fishing and that the minimum SPR should be higher than 30%.

[94] For, example in 2002 in the Ho’omalu zone reported bycatch of opakapaka was <1%, but the bycatch of butaguchi, kalekale, white ulua and kahala ranged from 20% to 100%, respectively (PIRO & WPFMC 2005).

[95] WPRFMC 2005b, Appendix A

[96] Restrepo *et al.* 1998

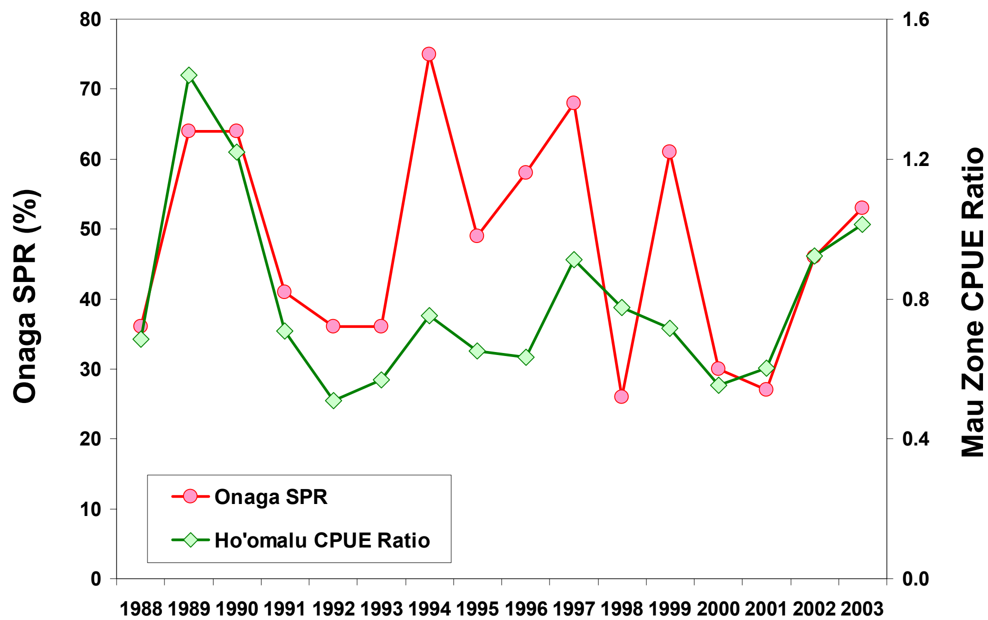

Figure 14. Comparison of Mau Zone SPR for onaga with the overall CPUE-ratio for the complex from 1988 to 2003.[97]

In the Ho'omalu Zone, where the analysis of CPUE data showed a steady decline in the stock complex, apparently headed for depletion, a similar decline from 1993 on can be seen clearly in the SPR estimates for onaga and hapu'upu'u (Figure 15). Onaga SPR values have gone from varying roughly between 50 and 100% prior to 1997, to varying roughly from 35 to 55% after 1996. SPR values for hapu'upu'u were higher but showed a very similar pattern of decline.

[97] CPUE data sources same as in Figure 8; SPR data extracted from figures in WPRFMC 2004.

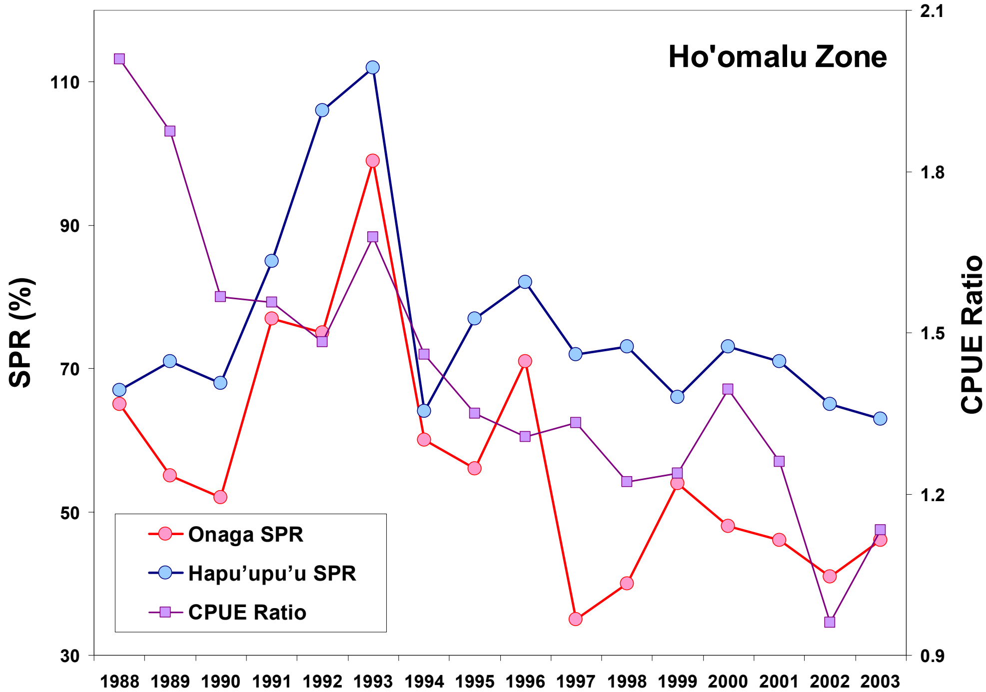

Figure 15. Comparison of Ho'omalu Zone SPR estimates for onaga and hapu'upu'u with the overall CPUE-ratio estimates for the complex.[98]

Another biological measure of the condition of a stock is the proportion of the catch that is made up of adult or immature fish. As discussed above, fishing tends to remove the largest individuals in the population, which are also the oldest individuals. Thus, as the average size and age of fish in the population declines, the proportion of adults in the catch declines and the proportion of immature fish increases. Because excessive removal of adult fish (spawners) can lead to a decrease in productivity and recruitment overfishing, the proportion of immature fish is sometime used to assess the condition of the stock and degree to which the spawning biomass may have been reduced. In a stable fishery being fished sustainably, this proportion should not show a trend over time. In the Ho'omalu Zone, onaga have shown a considerable change in the percent immature in the catch from 1984 to 2003, going from roughly 20% at the beginning of the period to 40-50% in recent years (Figure 16). This is a large change in a short period of time and may indicate an ongoing depletion of onaga spawning biomass in the Ho'omalu Zone.

[98] CPUE data sources same as in Figure 8; SPR data extracted from figures in WPRFMC 2004.

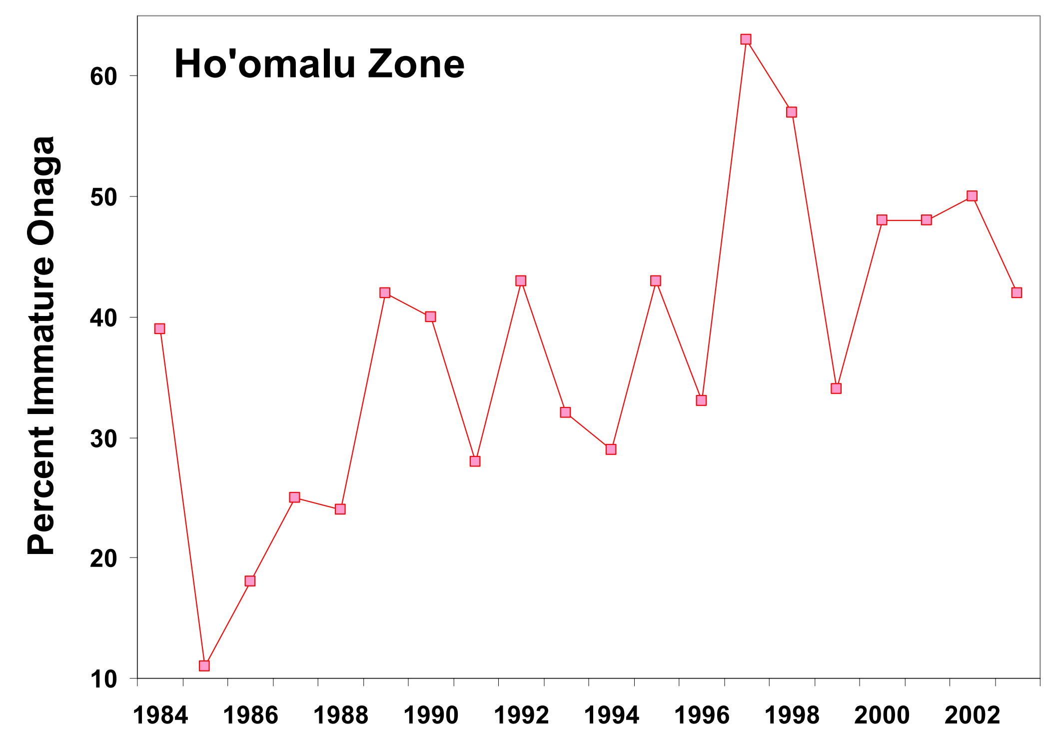

Figure 16. Changes in the percentage of immature onaga in the Ho'omalu Zone from 1984 to 2003.[99]

Similarly, a stable, sustainable fishery should not exhibit trends in the mean weight or size of fish. However, declines in the mean weight of fish have occurred from 1984 to 2003 for three species (uku, onaga and ehu) in both zones, another indication that fishing is continuing to deplete the stock complex in the NWHI (Figure 17).

[99] Data extracted from figures in WPRFMC 2004.

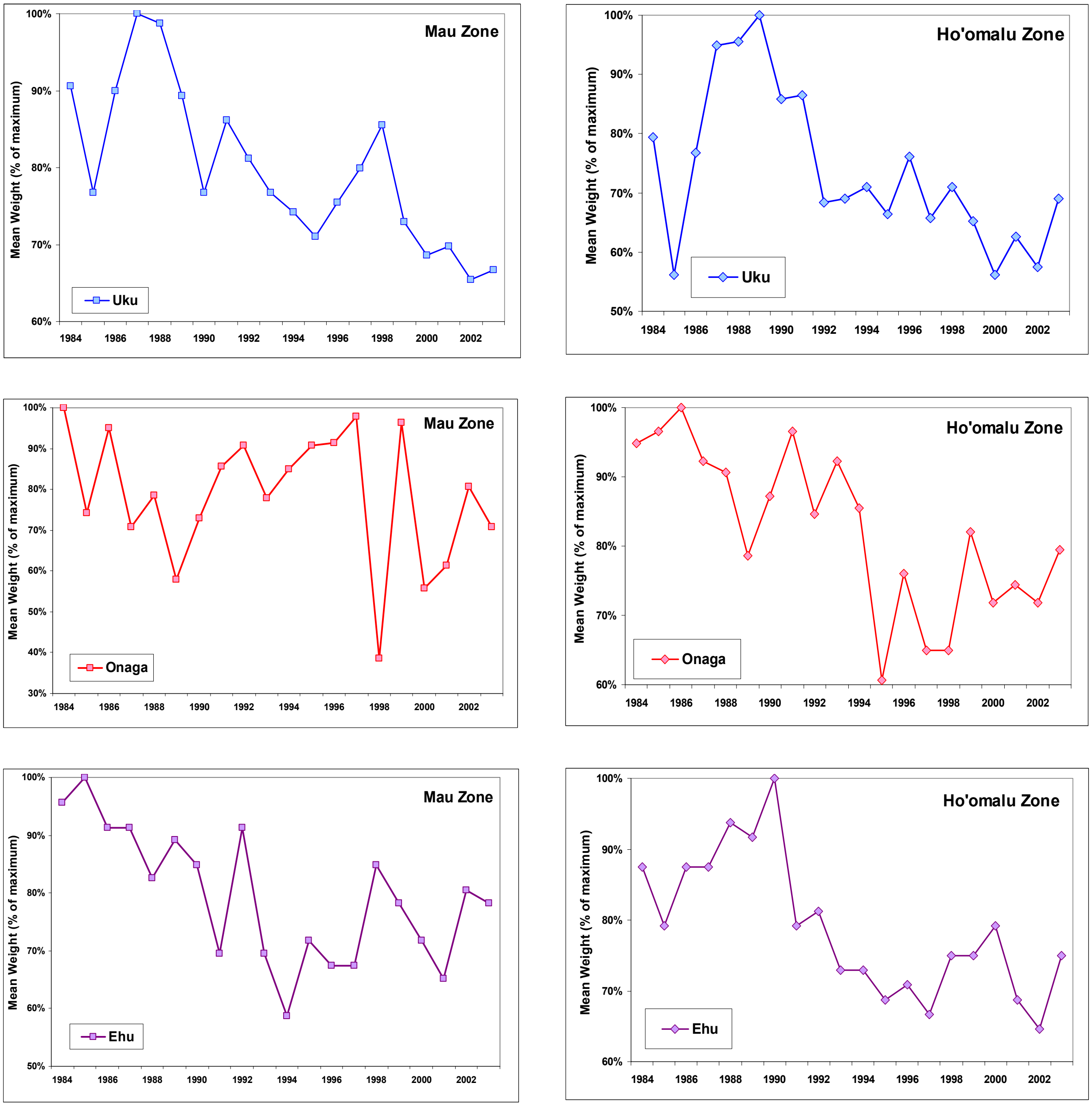

Figure 17. Changes in mean individual weight of uku, onaga and ehu in the Mau and Ho'omalu Zones from 1984 to 2003; data are presented as a percentage of the maximum value recorded during the period for the given species and zone to facilitate comparison among graphs.[100]

[100] Data extracted from figures in WPRFMC 2004.

A major concern with stocks that are managed as a complex is that some populations within the complex will be impacted to a much greater extent than the complex as a whole, and could be driven to very low levels without being detected. This phenomenon appears to be taking place in the Ho'omalu Zone, where opakapaka and hapu'upu'u have declined in abundance at a much faster rate than the complex as a whole (Figure 18). The biomass index for opakapaka in 2003 is only 10% of what it was just ten years before in 1993.

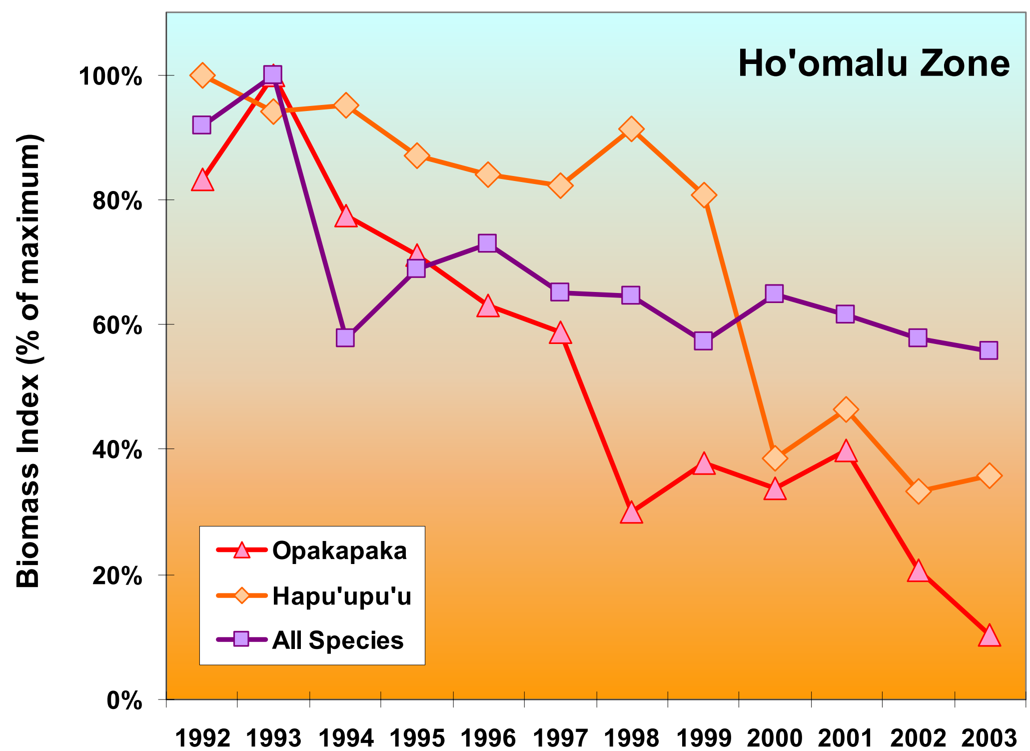

Figure 18. Declines in the biomass index (CPUE) from 1992 to 2003 (as a percent of the maximum value recorded during the period) for opakapaka and hapu'upu'u relative to that for the entire complex.[101]

Could Effort Effects Account for the Patterns?

The Western Pacific Fishery Management Council has suggested that declines in bottomfish CPUE in the NWHI can be explained by the entry and departures of highliners (vessels that are much more effective at catching bottomfish than the rest of the fleet), and by changes in the degree to which vessels spend time fishing for bottomfish or pelagics.

We note that the entry and exit of a highliner would tend to cancel each other out and not lead to a trend in CPUE. While the departure of a highliner could result in a decrease in the average CPUE

[101] The index values used here were lbs/trip; data in lbs/day were not available; data extracted from figures in WPRFMC 2004.

within the zone, its entry sometime earlier would have had the opposite effect (increase in average CPUE). Thus, it would take the repeated departures of highliners without corresponding entries to produce a long-term downward trend in CPUE. Such a pattern of exits without entries seems unlikely. In addition, we note that decreases in the CPUE index because of the exit of a highliner assumes that vessels with the greatest catches are also the vessels with the greatest CPUE. In other words, the most effective vessels are also the most efficient. However, we have not seen the data that would confirm this assumption.

Nonetheless, we examined the data for evidence that entries or departures have produced predictable changes in CPUE. With respect to the Mau Zone, the only data available to us on entries and exits of highliners[102] are the following statements that have been made in the Final and Draft Bottomfish Environmental Impact Statements:[103]

- "In 1994, a full-time commercial bottomfish fisherman entered the Mau Zone fishery and immediately made a large impact on the total landings for the duration of its participation through mid-1997."
- "The Mau Zone landings decreased 9 percent [in 2000], mainly due to the exit of one full-time bottomfishing vessel."
- "Declines [in 2000] in CPUE for this zone [Mau] may be largely due the departure of highliners [this appears to be at least a reference to the departure of the highliner in 1997] and greater concentration on other fishing methods, e.g. trolling … ."
- "Although the Mau Zone lost a vessel [in 2002], there were some vessels that did increase their targeting of bottomfish…."

[102] The complete data set on highliner entries and exits has been requested from the NMFS Pacific Islands Fisheries Science Center, Honolulu, but that request has not yet been acknowledged.
[103] PIRO & WPFMC 2004, 2005

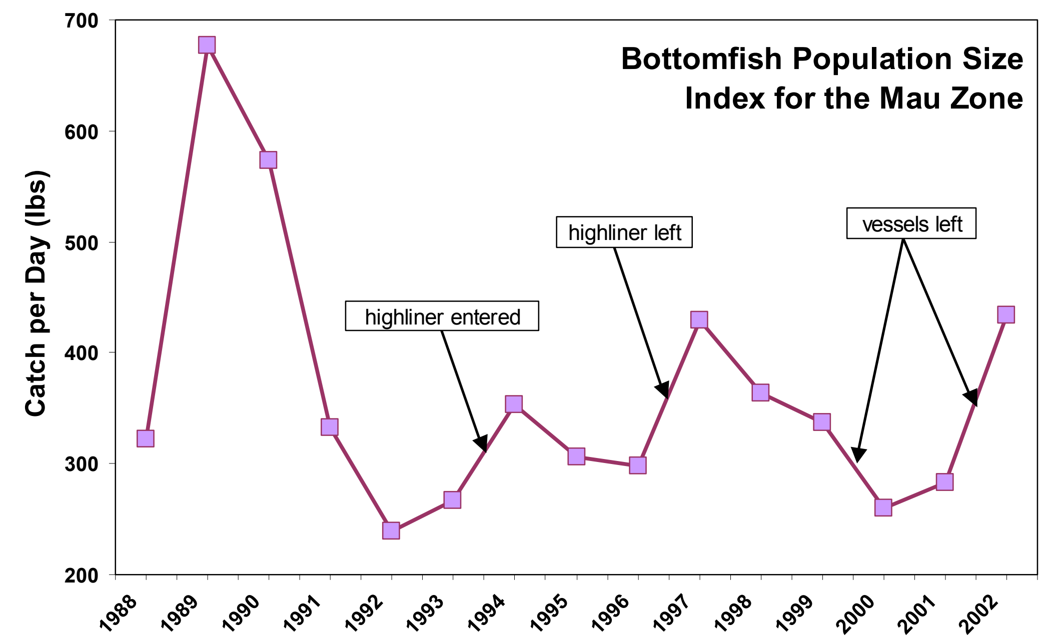

Figure 19. Entries and exits of highliners and other vessels from the Mau Zone fishery relative to the CPUE index.[104]

A visual assessment of the effect of these exits and entries in the Mau Zone can be obtained from Figure 19. It is certainly true that the movement of highliners, especially in a fishery with such a small number of vessels, could affect the distribution of effort in obvious ways. In addition, it is possible for the entry of a highliner to cause an increase in mean CPUE; this would occur if the highliner was much more efficient than the other vessels. Likewise, the departure of a highliner could cause a decrease in CPUE without any underlining change in the size of the stock. However this hypothesis is not borne out by the few examples supplied by NMFS and the WPFMC (Figure 19). While the entry of a highliner into the Mau Zone in 1994 was accompanied by an increase in CPUE, as claimed by the WPFMC, the catch rate declined the next two years during which time the highliner remained in the fishery. The departure of this highliner in mid-1997 was accompanied by a large increase in CPUE, rather than the decrease that might be expected when a highliner leaves. In 2000 there was a large decrease in CPUE from 1999 that was associated with the departure of a vessel, however the departure of another vessel prior to 2002 was associated with a large increase in CPUE. We have not been able to find any reference to entries or departures that might be associated with the large changes in CPUE seen in 1989 and 1991, and the changes seen at other times are not consistent with WPFMC claim that the changes in CPUE are due to the exit of highliners.

[104] Data sources same as in Figure 8.

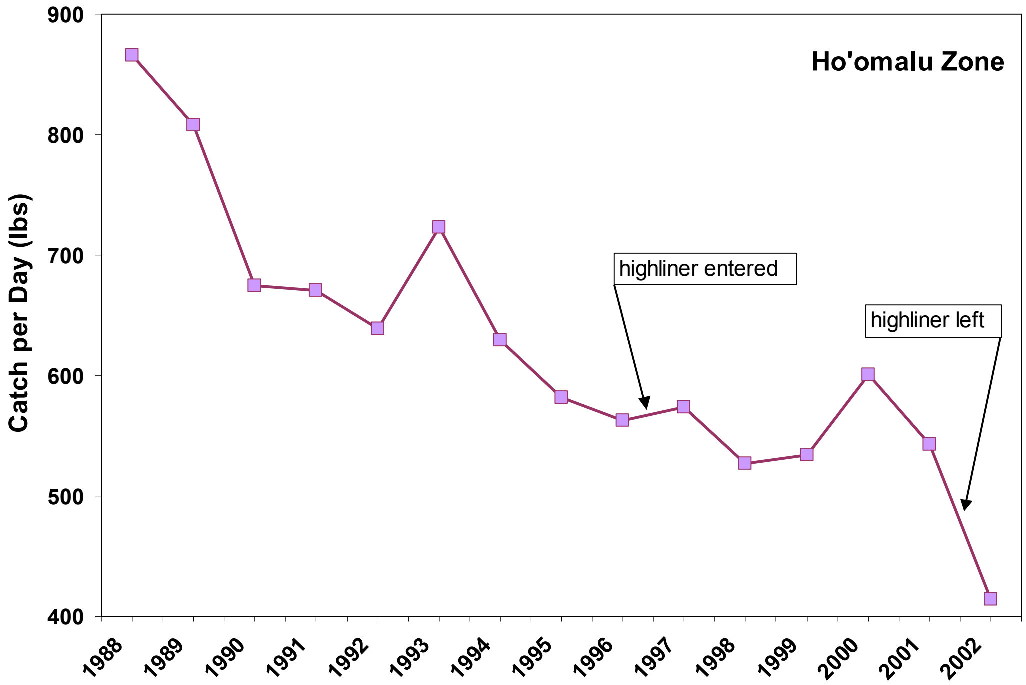

Figure 20. Entries and exits of highliners and other vessels from the Ho'omalu Zone fishery relative to the CPUE index.[105]

The effect of highliner movements is potentially a more important issue for the Ho'omalu Zone because of the significant decline in the bottomfish complex there from 1988 to 2002. Council and NMFS statements relative to this issue are:[106]

- "The Ho'omalu zone lost a single participating highliner vessel [in 2002] and the effects of that loss were realized in the 49% decrease in landings … [and] the number of trips there decreased by 36%. … Declines in CPUE for this zone may be largely due to the departure of highliners … ."
- "The same highliner vessel [as departed the Mau Zone in 1997] then entered the Ho'omalu Zone fishery late in 1997 and made an immediate impact on the volume of landings … ."
- "… the 2000 CPUE increased 13-14 percent over 1999 values on both a daily and trip basis. This may be due to the recent entry of a highliner from the Mau Zone." [presumably this is referring to the entry three years earlier]

Once again the evidence is equivocal. The entry in 1997 was associated with a very small increase in CPUE, followed by a decline and very small increase in the next two years. A moderate increase did occur from 1999 to 2000, but without additional data we can't know if that increase was due to the highliner. If it was, then it doesn't explain the lack of increases in the previous two years. While the departure of the highliner in 2002 was associated with a large decline in CPUE there was a

[105] Data sources same as in Figure 8.
[106] PIRO & WPFMC 2004, 2005

moderate decline in the previous year when that vessel was still fishing in the zone. In short, there is little evidence of a consistent correspondence between the movement of highliners and changes in CPUE. In fact, in the same documents cited above the WPFMC and NMFS reported "… up until 2002 the Ho'omalu fleet had very stable participation and landings for the last 7-8 years", during which time the CPUE index experienced relatively large fluctuations. Most importantly, even the changes that are consistent with the proposed explanation cannot account for the long-term, on-going decline in CPUE in the Ho'omalu Zone (Figure 9).

There has also been the suggestion that declines in CPUE could be due not to decreasing biomass of the stocks (as CPUE is assumed to indicate), but to unmeasured changes in bottomfishing effort. The measure of effort that is available is days fished. However, not all fishing effort is expended in bottomfishing. Some portion of the time is spent trolling for pelagic fish. Hypothetically, if we assume that stock sizes were roughly constant (no trend), and total effort was not changing, then a decrease in the proportion of time spent bottomfishing over time would produce a declining CPUE, which could be mistakenly interpreted as a decrease in stock size.

To examine this idea we used data on the size of the bottomfish catch and pelagic catch that were available for 1988 – 1996. If we assume that the proportion of the catch made up of bottomfish can serve as a proxy for the proportion of time spent bottomfishing, then the former can be used to adjust the corresponding effort measure. For example, if 8 days were spent fishing on average and 75% of the catch was bottomfish, then the adjusted effort would be 6 days, from which one could calculate an adjusted CPUE. If the hypothesis proposed above was correct, then any decrease in CPUE would be reduced or eliminated when examining the adjusted CPUE data.

We applied this approach to the 1988 – 1996 data from the Ho'omalu Zone, where the unadjusted CPUE showed a clear decline over that period. The hypothesis was not supported, however, as the adjusted CPUE suggested an even steeper decline, which resulted from the fact that the proportion of bottomfishing apparently increased over the time period (Figure 21).

Conclusions

We can see little consistent evidence that other factors provide compelling explanations for the patterns in effort and CPUE seen in the two zones. Furthermore, data from other biological reference measures corroborate the patterns of overfishing and overfished status. Combined with the evidence that biomass in the Mau Zone has been at or very near the overfished threshold and that it is rapidly approaching that threshold in the Ho'omalu Zone, the species data on SPR–percent immature and mean–length all show that the fishing rate in both zones is excessive and causing the ongoing depletion of certain bottomfish species in the Northwestern Hawai'ian Islands.

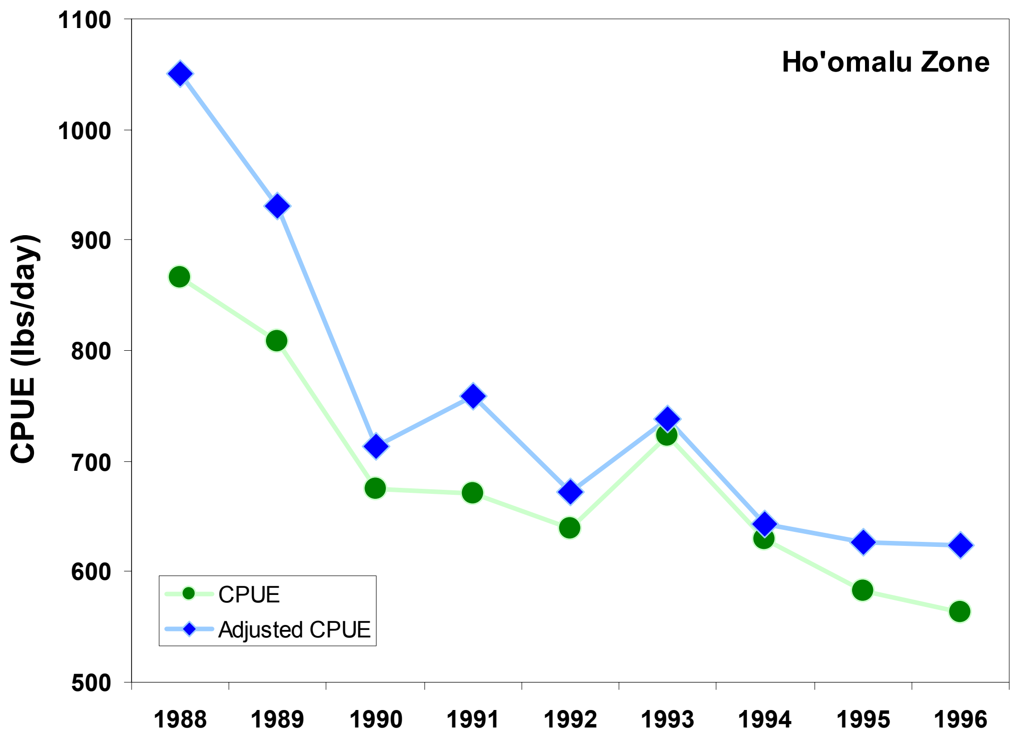

Figure 21. CPUE index and adjusted index compared for 1988 – 1996 in the Ho'omalu Zone.[107]

While we have yet to learn the specific ecosystem roles played by these bottomfish in the NWHI, there can be little doubt that severely reducing the abundance of a community of predatory fish through overfishing–with related bycatch effects–will produce significant ecosystem impacts.[108] These species are part of deep-water habitats that support many other species, including precious corals. The high-levels of endemism that have been recorded in more shallow habitats are likely to be mirrored in the deep-water habitats.[109] Thus, consideration of the impacts fishing on bottomfish in the context of adherence to Federal and State conservation objectives for the Northwestern Hawai'ian Islands makes it clear that commercial bottomfishing is an incompatible use of the Northwestern Hawai'ian Islands.

[107] The index was adjusted by reducing the effort measure used by the portion of total days fished that were spent fishing for pelagics; data collated from several bottomfish annual reports available on the Pacific Islands Fisheries Science Center web page.

[108] Tegner & Dayton 1999; Chuenpagdee et al. 2003; Myers & Worm 2003; Frank *et al.* 2005

[109] Friedlander *et al.* 2005

References

Aeby GS, JC Kenyon, JE Maragos and DC Potts. 2003. First record of mass coral bleaching in the Northwestern Hawai'ian Islands. *Coral Reefs 22(3): 256.*

Barot S, M Heino, L O'Brien and U Dieckmann. 2004. Long-term trend in the maturation reaction norm of two cod stocks. *Ecological Applications 14(4): 1357-1271.*

Berkeley SA, MA Hixon, RJ Larson and MS Love. 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries 29(8): 23-32.*

Birkeland C and PK Dayton. 2005. The importance in fishery management of leaving the big ones. *Trends in Ecology and Evolution 20(7): 356-358.*

Case T. 2005. "A Bill to Designate the Northwestern Hawai'ian Islands National Marine Refuge, and for Other Purposes." *109th Congress. 1st Session.*

Chuenpagdee R, LE Morgan, SM Maxwell, EA Norse, and D Pauly. 2003. Shifting gears: assessing collateral impacts of fishing methods in US waters. *Frontiers in Ecology and the Environment 1(10): 517–524.*

Clinton WT. 2000. "Executive Order 13178 of December 4, 2000. Northwestern Hawai'ian Islands Coral Reef Ecosystem Reserve." *Federal Register 65 (236): 76903-76910.*

Clinton WT. 2001. "Executive Order 13196 of January 18, 2001. Final Northwestern Hawai'ian Islands Coral Reef Ecosystem Reserve." *Federal Register 66 (15): 7395-7397.*

Coleman FC, CC Koenig, GR Huntsman, JA Musick, AM Eklund, JC McGovern, RW Chapman, GR Sedberry and CB Grimes. 2000. AFS policy statement on long-lived reef fishes - the grouper-snapper complex. *Fisheries 25(3): 14-20*.

Conover DO, SA Arnott, MR Walsh, and SB Munch. 2005. Darwinian fishery science: lessons from the Atlantic silverside (*Menidia menidia*). *Canadian Journal of Fisheries and Aquatic Science 62(4): 730-737.*

DeMartini EE, GT DiNardo and HA Williams. 2003. Temporal changes in population density, fecundity and egg size of the Hawai'ian spiny lobster (*Panulirus marginatus*) at Necker Bank, Northwestern Hawai'ian Islands. *Fishery Bulletin 101: 22-31.*

DLNR - Division of Aquatic Resources. 1998. "Current Line. Fish Facts for Bottom Fishes of Hawai'i." *Hawai'i Department of Land and Natural Resources, Honolulu, Hawai'i*.

DLNR. 2005. "Hawai'i Administrative Rules, Title 13: Department of Land and Natural Resources, Subtitle 4: Fisheries, Part II: Marine Fisheries Management Areas, Chapter 60.5: Northwestern Hawai'ian Islands Marine Refuge." *Department of Land and Natural Resources, State of Hawai'i, Honolulu.*

Ehler R. 2004. "Socio-Economic Assessment of Commercial Bottomfishing in the Northwestern Hawai'ian Islands." *National Marine Sanctuary Program, Silver Spring, MD.*

Friedlander AM and EE DeMartini. 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawai'ian Islands: the effects of fishing down apex predators. *Marine Ecology Progress Series 230:253–264.*

Friedlander A, G Aeby, R Brainard, A Clark, E DeMartini, S Godwin, J Kenyon, R Kosaki, J Maragos and P Vroom. 2005. The state of coral reef ecosystems of the Northwestern Hawai'ian Islands. *In: J. Waddell (editor), "The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005." NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD*.

Frank KT, B Petrie, JS Choi and WC Leggett. 2005. Trophic cascades in a formerly cod-dominated ecosystem. *Science 308: 1621-1623.*

Godvin, T. 2005. "Fishing Banned in NW Isles." *Honolulu Star Bulletin 10(273), September 30, 2005.*

Harman RF and AZ Katekaru. 1988. "Hawai'i Commercial Fishing Survey 1987." *Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawai'i.*

Jahanos TC and JD Baker. 2004. "The Hawai'ian Monk Seal in the Northwestern Hawai'ian Islands, 2001." *NOAA Technical Memorandum NMFS-PIFSC-1.*

Jokiel PL and EK Brown. 2004. Global warming, regional trends and inshore environmental conditions influence coral bleaching in Hawai'i. *Global Change Biology 10: 1627-1641.*

Office of the Governor. 2005. "Governor Lingle Signs Rules Establishing Marine Refuge In Northwestern Hawai'ian Islands." Press release September 29, 2005. Office of the Governor, State of Hawai'i.

Maragos J and D Gulko (editors). 2002. "Coral Reef Ecosystem of the Northwestern Hawai'ian Islands: Interim Results Emphasizing the 2000 Surveys." *U.S. Fish and Wildlife Service and the Hawai'i Department of Land and Natural Resources, Honolulu, Hawai'i.*

Moffitt RB and DR Kobayashi. 2000. "Recommended Overfishing Definitions and Control Rules for the Western Pacific Regional Fishery Management Council's Bottomfish and Seamount Groundfish Fishery Management Plan." *Southwest Fisheries Science Center Administrative Report H-00-03.*.

Myers RA and B Worm. 2003. Rapid worldwide depletion of predatory fish communities. *Nature 423: 280–83.*

NMFS. 1991. "Amendment 3 to the Fishery Management Plan for Pelagic Fisheries of the Western Pacific Region." *Federal Register 56 (202): 52214, Friday, October 18, 1991.*

NMFS. 2005. "Overfishing Determination on Bottomfish Multi-Species Stock Complex; Hawai'ian Archipelago." *Federal Register 70 (113): 34452-34453, Tuesday, June 14, 2005.*

NOAA. 2004. "Proposed Northwestern Hawai'ian Islands National Marine Sanctuary. Advice and Recommendations on the Development of Draft Fishing Regulations Under the National Marine Sanctuaries Act Section 304(a)(5). September 20, 2004." *National Oceanographic and Atmospheric Administration, Washington, DC*.

Olsen EM, M Helno, GR Lilly, MJ Morgan, J Brattey, B Ernande and U Dieckmann. 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. *Nature 428: 932-935.*

PIFSC WPacFIN "Bottomfish Fishery" web page. *Pacific Islands Fisheries Science Center, Western Pacific Fishery Information Network*.

PIRO. 2004. "Pacific Islands Region Bycatch Reduction Implementation Plan FY04-FY05." *National Marine Fisheries Service Pacific Islands Region Office, Honolulu, Hawai'i, and Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i*.

PIRO & WPFMC. 2004. "Draft Environmental Impact Statement. Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region. May 2005." *National Marine Fisheries Service Pacific Islands Region Office, Honolulu, Hawai'i, and Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i*.

PIRO & WPFMC. 2005. "Final Environmental Impact Statement. Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region. May 2005." *National Marine Fisheries Service Pacific Islands Region Office, Honolulu, Hawai'i, and Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i*.

Polovina JJ and WR Haight. 1998. Climate variation, ecosystem dynamics, and fisheries management in the Northwestern Hawai'ian Islands. *In: Ecosystem Approaches for Fisheries Management, pp. 23-32. University of Alaska Seagrant.*

Polovina JJ and RB Moffitt. 1980. "Commercial Bottomfish Handline Fishery in the Northwestern Hawai'ian Islands, 1959-77." *Southwest Fisheries Center Administrative Report H-80-11.*

Ralston S, S Cox, M Labelle & C Mees. 2004. "Bottomfish Stock Assessment Workshop. January 13-16, 2004. Final Panel Report." *Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i*.

Restrepo VR, GG Thompson, PM Mace, WL Gabriel, LL Low, AD MacCall, RD Methot, JE Powers, BL Taylor, PR Wade and J F Witzig. 1998. "Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act." *NOAA Technical Memorandum NMFS-F/SPO-31*

Rivera MAJ, CD Kelley and GK Roderick. 2004. Subtle population genetic structure in the Hawai'ian grouper, *Epinephelus quernus* (Serranidae) as revealed by mitrochondrial DNA analyses. *Biological Journal of the Linnean Society 81: 449-468*.

Tegner MJ and PK Dayton. 1999. Ecosystem effects of fishing. *Trends in Ecology and Evolution 14(7): 261-262.*

U.S. Congress. 1996. "The Sustainable Fisheries Act. An Act to Amend the Magnuson Fishery Conservation and Management Act to Authorize Appropriations, to Provide for Sustainable Fisheries, and for Other Purposes." *Public Law 104-297, 104th Congress.*

Wilcox B, K Duin, J Shafer and D Shafer. 2004. "Supplementary Notes on Decision Criteria, Information Synthesis, and Findings: Fishing in the Proposed Northwestern Hawai'ian Islands National Marine Sanctuary. *Sustainable Resources Group Int'l, Inc., Honolulu, Hawai'i.*

WPRFMC. 1986a. "Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region. Final. July 1986." *Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i.*

WPRFMC. 1986b. "Combined Fishery Management Plan, Environmental Assessment and Regulatory Impact Review for the Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region. Final. March 1986." *Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i.*

WPRFMC. 1990. “Amendment 3 and Environmental Assessment. Fishery Management Plan for the Bottomfish and Seamount Groundfish fo the Western Pacific Region.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2002a. “Magnuson-Steven Act Definitions and Required Provisions. Overfishing Provisions.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2002b. “Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region. 2002 Annual Report.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2003a. “The History of Fishing in the Northwestern Hawai’ian Islands.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2003b. “Managing Marine Fisheries of Hawai’i and the U.S. Pacific Islands – Past, Present, and Future. *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2004. “Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region. 2003 Annual Report.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2005a. “Background Paper and Options to Address ‘Overfishing’ in the Hawai’i Bottomfish Fishery.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*

WPRFMC. 2005b. “Recommendation of the Western Pacific Regional Fishery Management Council Regarding the Management of Fisheries within the Proposed Northwestern Hawai’ian Islands National Marine Sanctuary.” *Western Pacific Regional Fishery Management Council, Honolulu, Hawai’i.*