Climate Variation, Ecosystem Dynamics, and Fisheries Management in the Northwestern Hawaiian Islands

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Abstract: A dramatic ecosystem shift from high to low carrying capacity occurred in the late-1980s in the northern portion of the Hawaiian Archipelago. This shift was observed for a range of trophic levels and species including seabirds, monk seals, spiny lobsters, and reef fishes. Coherent with the ecosystem shift were physical changes associated with weakening of the Aleutian Low Pressure System and the Subtropical Counter Current. A trap fishery operating at Maro Reef rapidly depleted the spiny population after the ecosystem shift. At an adjacent bank, Laysan Island, closed to commercial lobster fishing, the spiny population declined much more gradually but ultimately was depleted as well. Harvest from the lobster fishery during much of the 1990s averaged about 25% of the 1980s harvest. Fishermen adjusted to the reduced harvest by moving into the pelagic longline fishery which was apparently not impacted by the ecosystem shift.

1. Introduction

The Northwestern Hawaiian Islands (NWHI) comprise a 1500 km chain of islands, atolls, coral reefs, and banks in the northern portion of the Hawaiian Archipelago (Figure 1). The region has no permanent human population but supports a rich marine ecosystem. In the mid-1970s a comprehensive research effort began to study various components of this ecosystem which led, in subsequent years, to standardized time series of indices of ecosystem productivity and population abundance for some components of this ecosystem. These indices and other survey data will be used to describe the sudden ecosystem shift which occurred concurrently with a climate shift in the late 1980s. One of the resources we will examine is the spiny lobster, which is targeted by a commercial trap fishery and hence provides an example of interactions between both fishery and climate impacts.

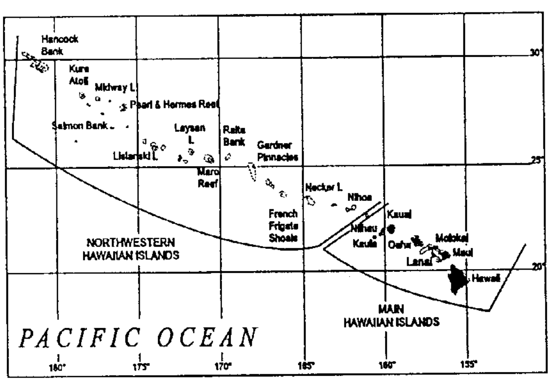

Figure 1. The Hawaiian archipelago.

2. The Climate Shift

A North Pacific climate event characterized by an intensification and southward shift in the Aleutian Low Pressure System occurred during 1977-88 (*Trenberth and Hurrell*, 1994). This climate shift impacted the northern portion of the Hawaiian Archipelago, probably through a southward shift of winter storm tracks and increased wind speed and stress, resulting in a deepening of the mixed layer depths by 30-80% during the winter (*Polovina et* al. 1995, *Polovina et al.* 1994). An ecosystem model of nitrate, phytoplankton, and zooplankton driven by mixed layer depth was used to evaluate the impacts to the plankton ecosystem from the lower light but greater nutrient levels caused by the deeper mixed layer depth during the 1977-1988 period. The model suggested that due to nutrient limitation in the NWHI, the deeper vertical mixing observed during this climate shift could increase both phytoplankton and zooplankton production by 50% (*Polovina et al.* 1995). Changes in vertical mixing are only one physical response, another is a change in horizontal transport. Data from tide gauges along the archipelago suggest that the Subtropical Counter Current (SCC) which crosses the northern portion of the Hawaiian Archipelago, was stronger during 1977-1985 and weaker subsequently (*Polovina and Mitchum*, 1992). A positive correlation between an index of the strength of the SCC and recruitment to the fishery 4 years later at Maro Reef has been documented (*Polovina and Mitchum*, 1992). It is not known whether the stronger SCC was the result of the more intense Aleutian Low or just coincidental, but both features were strong from 1977 until the mid-1980s and then shifted to weaker states which have persisted at least through the mid-1990s. Coherent with this shift in these physical features, we observed a drop in ecosystem carrying capacity in the NWHI which we believe resulted from this climate shift.

3. The Ecosystem Shift

Time series of indices of productivity for spiny lobster *(Panulirus marginatus)* the Hawaiian monk seal (*Monachus schauinslandi*), and two species of seabirds, the red-footed booby (*Sula sula*) and the red-tailed tropicbird (*Phaethon ruricauda*) all show declines between the 1980s and 1990s (Figure 2). In the case of spiny lobsters, indices of recruitment of 3-year-olds at two banks, Necker Island and Maro Reef, are measured as the catch rates from an annual standardized research survey. At Maro Reef 3-year- old recruitment completely collapsed in the late 1980s and has not shown any recovery since, while at Necker Island, 750 km southeast of Maro, recruitment dropped about 50% in the late 1980s but has shown some subsequent recovery (Figure 2). Monk seal pup survival, measured as the fraction of pups born which survive to age-2, showed a sharp decline at French Frigate Shoals (FFS) in the late 1980s with no subsequent recovery, while at Laysan, north of FFS, the decline is more gradual (Figure 2). For both species of seabirds at FFS reproductive success, measured as the fraction of eggs laid which result in fledgling chicks, \ shows a sharp drop of about 50% between the early 1980s and the period since the mid-1980s (Figure 2). When lobster and monk seal time series are shifted backwards 2 or 3 years to account for the appropriate time lags (lobster data are for 3-year-olds, monk seal data are based on 2-year olds) temporal coherence between the time series is seen. While the causes of these declines have not been completely determined, in the case of monk seals and seabirds field observations suggest reduced food availability during their winter fledgling season is a likely factor. A reduction in food availability has been cited as the reason for declines in reproductive success in other sea bird populations (*Baird*, 1992). In the NWHI in the 1990s, the higher egg mortality appears to be the result of longer exposure to the sun and higher chick mortality to be the result of starvation, all of which are consistent with lower food availability for adults resulting in more time spent away from the nest foraging and less food for the chicks. These seabirds forage primarily on flying fishes and squids which are linked to oceanic rather than reef productivity.

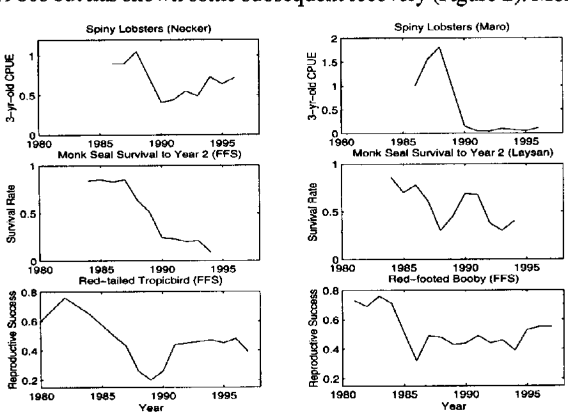

Figure 2. Time series of indices of productivity for seabirds, monk seals, and spiny lobsters in the NWHI.

The decline in monk seal pup survival has also been inferred to be the result of a decline in prey, based on widespread observations of emaciated pups and the lack of other identifiable causes including direct human impacts and disease (*Gilmartin and Ragen*, 1992). The diet of monk seal pups is not known but generally the areas and depths where they are seen foraging suggest they forage on prey in the benthic coral reef and shelf ecosystem. Like the seabirds, winter appears most critical to monk seal pup survival since the pups first forage then.

The reef fishes are a major component of the NWHI ecosystem, and given the remote location of the region, are not impacted by human exploitation. While a continuous time series of reef fish densities is not available, comparisons between densities at the same reefs at French Frigate Shoals and Midway Atoll between the early 1980s and early 1990s show that densities in the early 1990s are about one-third lower than in the early 1980s, providing still another indication of the drop in carrying capacity seen in other elements of the ecosystem *(DeMartini et al.* 1996).

4. Climate and Fishery Interactions

The catch rate of 3-year old spiny lobsters at Maro Reef, obtained from standardized research cruises and used as an index of recruitment to the fishery, showed a dramatic collapse in 1990 (Figure 2). Age composition of the trap catches from these research cruises show an abundance of 3-year-olds along with some older and younger lobsters in 1987 and 1988, but since 1990 and persisting through the present, the spiny lobster population at Maro Reef appears to be severely depleted (Figure 3). Unfortunately, 1989 age-frequency data which might show a transition between 1988 and 1990 levels are not available due to the lack of a research cruise in 1989.

Maro Reef and Necker Island were the two primary fishing grounds for the lobster trap fishery during the 1980s, and annual

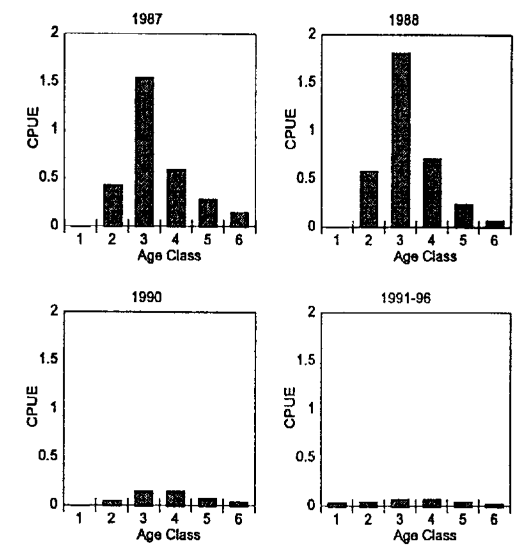

Figure 3. Age-frequency of spiny lobsters from Maro Reef research cruises.

harvest at Maro Reef during that period ranged from about 200,000 to 450,000 lobsters (Figure 4). The picture from Figures 2-4, suggests a collapse in recruitment of 3-year old spiny lobsters

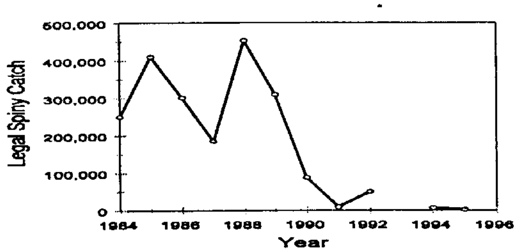

Figure 4. Commercial landings of spiny lobsters from Maro Reef.

to the fishery in 1989, as a result of a sudden weakening of the SCC during the mid-1980s (*Polovina and Mitchum*, 1992). The fishery was largely harvesting a single age group, 3 year olds, and with the collapse in recruitment to the fishery in 1989, the remaining population of older lobsters was quickly depleted by the fishery.

Laysan Island, about 110 km north of Maro Reef, has been closed to commercial lobster trapping since the beginning of the fishery to protect the large population of monk seals on Laysan from becoming entangled with lobster traps and line. Limited research trapping at Laysan shows an absence of 2- and 3-year-olds in 1991 compared to 1977 and 1986, suggesting that the recruitment collapse which impacted Maro Reef also impacted Laysan by 1991 (Figure 5). However, apparently due to the absence of a fishery at Laysan, unlike at Maro Reeft, there was still a significant population of older animals at Laysan . Unfortunately by 1996, even in the absence of a fishery the lobster population at Laysan was severely depleted, apparently the result of the collapse of recruitment in the mid-1980s and the subsequent impact of natural mortality (Figure5).

5. Response of Fisheries Management

Since 1983, the fishery has been regulated under a Fishery Management Plan by the Western Pacific Regional Fishery Management Council (WPRFMC) primarily with a minimum size set slightly above the size at onset of maturity, escape vents in traps to allow escapement of sublegal lobsters, and some areas closed to fishing. These closed areas, although were not specifically designed to protect lobsters but rather to reduce fishery interactions with protected species, did close perhaps as much as 10% of the lobster habitat to trapping, including all of Laysan Island and all portions of banks shallower than about 20 m.

The sudden collapse of the spiny lobster population in 1990 caught fisheries managers by surprise. In 1989 a dynamic production model was used with historical commercial fishery data to estimate a maximum sustainable yield (MSY) for the NWHI fishery (slipper and spiny lobsters combined) of 1 million lobsters, with an effort of 1 million trap-hauls (Polovina, 1990). The 1989 fishery catch and effort of about 1.2 million lobsters and 1.1 million trap-hauls suggested the fishery was at about MSY levels. However, by 1990 it was obvious that the population of spiny lobsters at Maro Reef and other northern banks had collapsed. The 1990 status of the stocks report noted that the spiny lobster spawning biomass in 1990 was estimated at 22% of the pre-fishery level and recommended both a seasonal closure, from January through August to protect spawning biomass and a reduction of annual effort to 200,000 trap-hauls (Polovina, 1991).

Catch and effort were not restricted during 1990, and about 775,000 lobsters were caught with 1.2 million trap-hauls. The collapse of a portion of the spiny lobster population in 1990 without any reduction in effort, meant that the performance of the fishery measured as the catch rate (the ratio of total catch divided by total effort) dropped 40% between 1989 and 1990. Prior to 1990, industry was not generally supportive of restrictions on catch or effort. Their argument was that it was unnecessary since the fishing grounds are remote and effort would cease once catch rates fell below an economically viable level which was sufficiently high to protect against recruitment overfishing. However, the 1990 season showed that there was excessive fishing capacity in the industry given the reduced population size and raised concern that an economic threshold might not prevent overfishing. Responding to this concern, the WPRFMC closed the fishery under an emergency closure from May 8 to November 11, 1991 and implemented new management regulations in 1992. These new measures added regulations to the existing management measures, including a closure during the first half of the year to protect spawning biomass and a harvest quota to control harvest during the second half of the year. Initially the new harvest quota approach resulted in high interannual variation, a combined slipper and spiny lobster NWHI harvest of about 850,000 for 1992 followed by a closure of the fishery in 1993. However, from 1994 to 1997 quotas have been in the range 101,000 - 310,000, well below the long-term MSY of 1 million lobsters estimated prior to the collapse at Maro Reef. Under this lower harvest, catch rates for spiny lobsters at Necker, have recovered about 50%, from 0.5 to 0.75 lobsters/trap-haul, but spiny lobsters at Maro Reef have not recovered since the 1990 collapse, although there has been a substantial increase in slipper lobsters at Maro Reef.

Recent research suggests that the source of spiny lobster larvae at Maro Reef is the spawning population at Maro Reef and hence

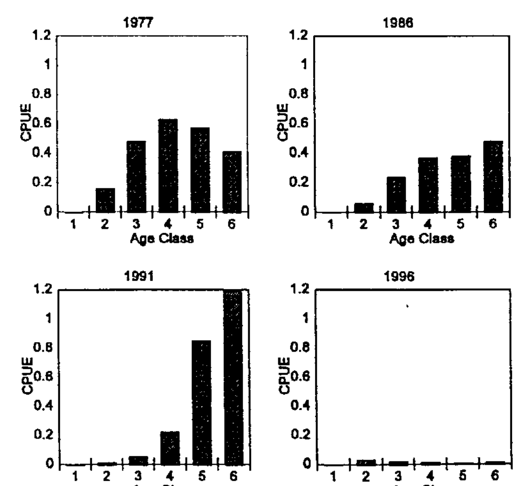

Figure 5. Age-frequency of spiny lobsters from Laysan Island research cruises.

at Maro Reef is the spawning population at Maro Reef and hence the recovery of the spiny population at Maro Reef may be a long, slow process based on rebuilding the resident spawning biomass (*Polovina et al.* in review). The industry has been generally supportive of the management action reducing harvest levels. One important reason for this support was that all 15 permit holders were also able to obtain permits for the pelagic longline or bottomfish fishery, so their economic condition was not tied solely to the lobster fishery.

In the absence of the evidence of a climate and ecosystem shift, management might have a goal of rebuilding the fishery to achieve an MSY of 1 million lobsters. This would require closing the fishery for an extended period, but it is unlikely this recovery is achievable under the current less productive regime. Current management action recognizes there is a much lower MSY under the new physical and ecosystem regime.

6. Summary

A shift in climate occurred in about 1989 in the central North Pacific characterized by a weakening of SCC and Aleutian Low Pressure System. The NWHI ecosystem shifted, apparently triggered by the climate shift, from a high carrying capacity to a low one. The shift occurred rapidly and nearly simultaneously over a range of trophic levels There are significant spatial patterns, for example, the drop in spiny lobster recruitment was greatest in the northern portion of its range while the drop in pup survival for monk seals was greatest at the southern end of its range. It is likely that there is not one physical cause for this ecosystem shift. In the case of lobster, evidence suggests that a reduction in lobster larval retention at Maro Reef occurred with the weakening of the SCC. In the case of seabird reproductive success and monk seal pup survival, evidence suggests a decline in prey arising from lower primary productivity attributed to weaker vertical mixing.

At Maro Reef, fishing prior to the drop in productivity reduced that population age structure making it less resilient to interannual recruitment variation. After the recruitment collapse, a few years of unrestricted fishing at Maro Reef quickly eliminated most of the remaining spawning biomass.These results illustrate interactions between fishing and climate shifts: fishing alters the age-structure and can rapidly deplete a stock when the ecosystem shifts to a regime of lower carrying capacity. At Laysan, protection from fishing preserved more of the age structure but after a decade of poor recruitment, the spawning biomass was apparently depleted from natural mortality. Thus marine reserves may not always provide the protection many proponents assume.

One consequence of the collapse in the spiny lobster fishery at Maro Reef is that it raised concern about the ability of open access management to protect the spiny lobster population and provided the impetus to managers and industry to move to a limited access fishery with harvest controls. The ability of management to reduce catch and effort to about one-fourth the level prior to the stock collapse at Maro Reef was greatly facilitated by the permit holders who all had permits for the pelagic longline fishery and were able to move into another fishery not impacted by the ecosystem shift. Therefore, one-step fisheries management can take to prepare for the impacts of climate variation is to encourage fishermen to diversify between fisheries that are not likely to fluctuate together. Unfortunately, the current trend toward limited access fisheries may restrict the ability of fishermen to diversify.

It has been a decade since the last climate and ecosystem shift. An issue of great interest to all those involved with the NWHI ecosystem is whether these states alternate on a decadal cycle so we can look forward to a return to a more productive period in the near future or whether these shifts are rare and irregular events.

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