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Pelagic Fisheries Research Program
university of hawai'i at mānoa

Volume 13, Number 1 January-April 2008

The Pacific-Atlantic Sea Turtle Assessment Project (PASTA): Bringing Disciplines Together to Evaluate the Causes of Sea Turtle Decline

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Introduction

Sea turtles are long-lived and wide-ranging. A loggerhead turtle hatched in Japan may, over the course of its juvenile development, spend two decades or more traversing the productive boundary currents of the North Pacific. Some may possibly travel as far as the shallow nearshore habitats of the Baja Peninsula to feed before swimming back to neritic regions near Japan or in the South China Sea. Sea turtles are also "charismatic megafauna" that are caught in various types of fishing gear, raising concern about the effects of fishing activity on populations.

Nesting-beach counts of sea turtles indicate dramatic declines, in many parts of the world, from historic records and over recent decades. All seven species of sea turtle are listed on the International Union for Conservation of Nature and Natural Resources Red List of Threatened Species and international trade of sea turtle eggs, meat, and shell is prohibited by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES).

Recovery Strategies

In developing effective recovery strategies it is critical to be able to predict how various stressors affecting sea turtles may be contributing to population declines. This is not an easy task. Human impacts and environmental variability affect turtles at different points in their life history and in different areas of their range. Given the difficulty of obtaining detailed information on existing sea turtle populations it has been nearly impossible to develop assessment models that accurately evaluate how specific stressors relate to observed population-growth rates on nesting beaches.

To address this problem we have begun a broad-scale cross-disciplinary examination of stressors affecting loggerhead and leatherback sea turtles. Our approach compares estimates of the intensity and relative impacts of fishing (pelagic and nearshore), direct harvest (eggs and adults), beach development, and climate change on populations of these two species in the Atlantic and Pacific oceans (Table 1).

Based upon the differences in estimated age at maturity (ca. fifteen years for leatherbacks and as high as thirty years for loggerheads), the two species provide an ideal opportunity to compare population responses.

Project Concepts

Our project is unique in our effort to combine the ideas and draw upon the expertise of scientists from a number of different disciplines: sea turtle biology and physiology, population dynamics, fisheries science, and oceanography. Our project has already generated multiple new theories regarding the causes of sea turtle declines and the role of pelagic fisheries in those declines. It has also promoted research partnerships that reach far beyond the typical approaches used to assess populations of threatened species.

Our comparative approach has generated a set of working hypotheses that we can evaluate both with existing data and with data we can reasonably expect to obtain in the near future. We have also identified critical gaps in existing research that must be addressed by management agencies to further clarify the causes of and identify the preventions needed for the reversal of sea turtle population decline.

Loggerhead Turtles

Loggerhead turtles (*Caretta caretta*) are hard-shelled slow-growing animals. They originate primarily on the warmer eastern sides of the two northern-hemisphere ocean basins between 20° and 35° latitude. Genetic and tag-recovery data suggest that this species does not cross the equator.

In the Northern Pacific all loggerheads originate from nesting beaches in the southern islands of Japan. Monitoring of these islands and their nesting beaches by the Sea Turtle Association of Japan has shown both increasing and decreasing trends in recent years (Table 2). Trends differ at different times because of data availability (fewer beaches monitored in the early years) as well as local and population-level responses to conservation efforts or stressors.

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Table 1. List of stressors noting, by species and ocean basin, which life stages are affected

Stressor	Life Stage Affected			
	Pacific Leatherback	Atlantic Leatherback	Pacific Loggerhead	Atlantic Loggerhead
Egg harvest	Eggs	Eggs	Eggs	Eggs (rare)
Adult female harvest	Nesters	Nesters	Nesters (rare)	Nesters (very rare)
Beach development	Nests, hatchlings Nesters (redistribute)	Nests, hatchlings Nesters (redistribute)	Nests, hatchlings Nesters (redistribute)	Nests, hatchlings Nesters (redistribute)
Nearshore fisheries	Nesters	Nesters Subadults and adults	Nesters Some subadults and juveniles (Baja)	Nesters Subadults and adults
Pelagic fisheries	Small juveniles, large juveniles, subadults, adults	Small juveniles, large juveniles, subadults, adults	Small juveniles, large juveniles, subadults, adults	Juveniles Some subadults, adults
Ocean productivity—pelagic	Hatchlings Juveniles (growth) Adults (nesting freq)	Hatchlings Juveniles (growth) Adults (nesting freq)	Hatchlings Juveniles (growth) Adults (nesting freq)	Hatchlings Small juveniles (growth) Adults (nesting freq)
Ocean productivity—shelf upwelling	Juveniles (growth) Adults (nesting freq)	Juveniles (growth) Adults (nesting freq)	Juveniles (growth) Adults (nesting freq)	Large juveniles (growth) Adults (nesting freq)

We are currently investigating the potential for a long-term population response due to high seas driftnetting in the 1980s, as well as local responses to beach armoring and development that could redistribute nesters to adjacent islands. Overall, the Japanese loggerhead nesting numbers have increased in recent years.

In the North Atlantic, 80–90 percent of loggerheads originate from nesting beaches in Florida. Additional nesting occurs north to Virginia with smaller populations in the Florida Panhandle and on the Yucatan Peninsula. In the eastern North Atlantic, these turtles nest in Greece and on the Cape Verde Islands off the coast of Africa. Loggerhead nesting in Florida was increasing in the early- and mid-1990s but has decreased by 50 percent since 1998.

Primary threats to these turtles include incidental drowning in bottom trawls, nesting-beach degradation, incidental capture on longline gear (bottom and pelagic), and gillnets and other coastal-fishing gear.

Loggerhead turtles are today rarely targeted for food, although eggs are harvested by local people in a few areas. Loggerheads are carnivores with a very broad diet including jelly organisms and portunid crabs in pelagic ecosystems and crabs and mollusks in continental-shelf ecosystems. Loggerheads can be roughly aged by noting the growth rings shown in their humerus bone.

Leatherback Turtles

Leatherback turtles (*Dermochelys coriacea*) are the largest living sea turtles and are quite different from the hard-shelled species. Leatherback shells consist of tiny calcified plates covered by a leathery skin. Although only a few juvenile leatherbacks have ever been collected, we believe that they grow very quickly. With their unique physiology and large body size they are effectively "warm-blooded," which allows sub-adult and adult animals to feed in latitudes as high as 50° N.

Leatherback turtles nest in tropical zones on both sides of each ocean basin. Nesting populations on the east side of the North Pacific have declined precipitously over the last two decades, sparking a strong conservation movement targeted at nesting-beach protection and fisheries restrictions. In the Western North Pacific, leatherbacks nesting in Malaysia have declined to effective extinction over the past two decades. Nesting beaches in Indonesia and Papua New Guinea appear to show stable or slightly declining status, although scientific monitoring there is relatively recent.

In the North Atlantic, leatherbacks originate primarily from mainland beaches in Suriname and French Guiana and from the island of Trinidad; these beaches show stable or increasing trends since 1990. The best-studied leatherback population is on the island of St. Croix. This population has been protected and intensively monitored since 1982. A small-but-rapidly-increasing nesting population in Florida is providing valuable information on how leatherbacks spread into "new" areas during periods of population increase.

Based upon genetic analyses and satellite tag tracks, it appears that only leatherbacks from the western North Pacific interact with northern pelagic fisheries. Nesting females from the eastern North Pacific tagged with satellite transmitters moved either south or west along the equator, rather than north. However it may simply be that eastern populations are now so low that numbers alone make it unlikely for these turtles to be encountered north of the equator.

As leatherback turtles largely feed on jellyfish and jelly-like organisms, following their food supply, they are primarily pelagic. Some individuals, however, do move into nearshore areas to feed in coastal upwelling zones. Primary threats to leatherbacks include gillnets and longline gear (leatherback losses from longline gear nearly always involve a hook snag rather than a hook swallow) and intentional harvesting for meat and eggs.

There is currently disagreement concerning the accuracy of aging leatherbacks, which is now done primarily by reading growth rings in sections of the bones that surround the eye.

Table 2. General trends in loggerhead and leatherback sea turtle nesting populations by ocean basin and hemisphere.

Population	Primary Nesting Beach Locations	Trend for 1975–1985	Trend for 1985–1995	Trend for 1995–2005
North Pacific Loggerheads	Japan	Unknown	Decreasing	Increasing
North Pacific Leatherbacks—east	Mexico, Costa Rica	Unknown	Decreasing	Decreasing
North Pacific Leatherbacks—west	Malaysia, Indonesia, Papua New Guinea	Unknown	Decreasing	Decreasing or stable
North Atlantic Loggerheads—east	Mediterranean, Cape Verde Islands	Unknown	Stable	Decreasing
North Atlantic Loggerheads—west	USA, Mexico	Decreasing	Stable or increasing	Decreasing
North Atlantic Leatherbacks—east	French Guiana, Guyana, Suriname, Caribbean	Stable or increasing	Stable or increasing	Increasing[1]
North Atlantic Leatherbacks—west	West coast and equatorial Africa	Unknown	Unknown	Unknown[2]

[1] With the exception of Costa Rica, which has shown a decline.
[2] Leatherback nesting has been recorded in many African countries, with the largest colonies in Gabon, but has not been monitored long enough to estimate a trend.

Assessing Current Status and Stressors

The National Marine Fisheries Service has been investigating the status of sea turtles in the Pacific and Atlantic oceans (Table 2) through the development of Expert Working Group Panels and Recovery Planning Teams. There have also been international synthesis meetings, such as the Bellagio Sea Turtle Initiative held in 2003, to discuss the status of Pacific sea turtles, and large-scale synthesis projects currently underway such as State of the World's Sea Turtles (SWOT) and the Global Bycatch Assessment of Longlived Species (Project GloBAL).

The Pacific-Atlantic Sea Turtle Assessment Project (PASTA) compliments these efforts by expanding the research perspective. PASTA focuses on identifying additional quantitative approaches to status evaluation and to examining patterns in the existing data that may correlate with factors such as climate change and human population growth. Sea turtle issues are broad and complex and require multiple efforts to identify primary stressors and the best solutions to promote population recovery.

Recent dynamics of the nesting populations of loggerheads and leatherbacks in the Atlantic and Pacific oceans are, overall, a response to ocean conditions, fishing activities, and management efforts. Our initial hypotheses for population change were based on the general trends observed in the 1990s: Atlantic populations stable or increasing; Pacific populations in decline. However recent data show a much more complicated pattern (Table 2). Not surprisingly, we have not identified a single "smoking gun" that points to a particular stressor as the primary factor for decline of some sea turtle stocks in the Pacific. However we have identified two important factors deserving of further research and consideration: the effects of ocean conditions on reproductive frequency and the importance of time lags in data evaluation. Both of these issues have a direct impact on how we interpret changes in the numbers of nests or the numbers of nesting females.

Fisheries Effects

The potential effects of fisheries bycatch on sea turtle populations was a major focus of our synthesis effort. Pelagic longline fishing effort is high in both northern hemisphere ocean basins. Annual fishing effort was higher in the Pacific than the Atlantic, both in terms of estimates of the absolute numbers of hooks—718 million vs. 316 million—as well as the estimate of hooks per km^2—4.4 vs. 3.4. However, there were no basin-wide differences in reported frequency of interaction with longlines (turtle catch per 1000 hooks).

In the Pacific, sea turtles are reported more often in gillnet bycatch data than in longline bycatch data. It is difficult to estimate the amount of gillnet effort in either ocean basin primarily because a large amount of gillnet effort is by local fishermen in coastal areas and is poorly documented. The mortality rate for turtles caught in gillnets is consistently higher than mortality rates estimated for longline gear, even when post-release mortality is considered.

Our initial synthesis suggests that pelagic longline impacts may be substantial due to the large number of turtles encountered overall, but gillnet fisheries are a major factor in coastal areas and need to be examined much more carefully. Demersal longline gear also deserves more attention, as does the continuing issue of trawl bycatch mortality in the US and elsewhere.

It is difficult to accurately estimate the number of turtles killed in fishing gear worldwide; it is even more difficult to determine the population-level impacts of those mortalities. There are currently no reliable estimates of the extent of the at-sea population. Long-term effects of fishing-gear deaths on turtles are dependent on which age classes are most affected, population reproductive productivity, and potential compensatory responses in growth, survival, or reproduction that are density-dependent. The last issue is often ignored in sea turtle population models. Current populations are at much lower densities than they were historically and there is little information on density-dependent growth or mortality for any species. Thus it is generally assumed that current demographic vital rates are unrestricted by population density issues and are at their biological maximum.

We compared the potential impacts of various fisheries on loggerhead populations using an estimate of the *reproductive value* of the size classes of turtles caught. Fisheries that bycatch large turtles

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that are mature or nearing maturity may have a larger overall impact than fisheries that bycatch the same number of smaller animals that are more likely to die naturally before reaching reproductive age.

Unfortunately, there are few fisheries data sets that include size distribution as well as mortality rates of bycatch. Our results indicate that Hawaiian longline fisheries affect smaller turtles with lower reproductive values than pelagic longline fisheries in the Atlantic. With our research partners in the Global Bycatch Assessment of Long-lived Species Project (GLoBAL, http://bycatch.env.duke.edu), we hope to accumulate more size-distribution information from different fisheries over the next few years.

Time-Lag Effects on Population Models and Trends

A second, and critical, synthesis effort underway is an assimilation of what is known about the distribution of turtles from different nesting areas in pelagic and neritic regions. Spatial overlap of fisheries and turtle foraging grounds holds great promise as a way to identify possible connections between fishing mortality and subsequent trends on nesting beaches. Time lags are an essential consideration for assessment.

In the Pacific, the "perturbation legacy" of high seas driftnetting in the 1980s may still be affecting recruitment to the nesting beaches for both species because of effects on productivity and cohort strength. Likewise, the current decline in Atlantic loggerhead nests in Florida may be driven in part by trawling mortality in the 1970s and 1980s.

Working with age-structured models configured to time series we can evaluate the possibility that current population trends are a result of fishing effort that occurred sometime in the past. We can also use the expected time lags to help distinguish the likely benefits of management efforts from population fluctuations that may be due to environmental change. Currently we are gathering information on the history of protection efforts at major nesting beaches to determine where and when large increases in productivity have occurred.

Sea turtles do not nest every year. This is likely due to the energy costs of long-distance migration across entire ocean basins or hemispheres and/or changes in food concentration or quality. Such factors can affect reproduction and can have a profound effect on the relationship between nests and adult female population size. In the Pacific, nesting leatherback females in Costa Rica have longer average remigration intervals and fewer nests than females observed in Indonesia. In Florida, many leatherback females nest annually and appear to be feeding in the continental shelf waters of the US and Canada. These waters have seen an increase in jellyfish abundance over the last decade.

Ocean-Condition Effects

There is a predictable relationship between ocean conditions and nesting frequency in green and loggerhead turtles in Australia. Further research should help to refine the data on this relationship for northern-hemisphere leatherbacks and loggerheads.

However trends in nest numbers must be evaluated cautiously and in relationship to data on nesting female condition and behavior.

Ocean conditions may also affect the dispersal and survival of hatchlings that leave nesting beaches as well as the distribution or quality of forage for juvenile turtles. Overall, the amount of primary productivity in areas that are believed to be sea turtle foraging grounds has increased more in the Atlantic than in the Pacific. This may be "fueling" populations of leatherbacks in the North Atlantic.

A model of surface-current vectors has been refined to show potential transport and distribution of hatchlings from different nesting beaches to see if broad-scale changes have occurred in time and space. Although surface currents are not the only influences on hatchling dispersal, they likely play a significant role at least for the first few months of life and provide another opportunity for evaluating the effects of changes in ocean conditions through time.

Conclusions

As with most threatened species, a range of natural and anthropogenic factors affect both sea turtle declines and recoveries. Our approach is providing a few new insights. More importantly, our approach has fostered new collaborative research that will contribute substantially to sea turtle assessments and conservation in the future.

We plan to continue annual meetings with our research partners, support publication of PASTA-related synthesis products, and expand our website outreach efforts. We welcome suggestions from and participation at future PASTA workshops by interested colleagues.

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Oceanographic Investigation of the American Samoa Albacore Habitat and Longline Fishing Grounds

Réka Domokos, Jeffrey Polovina, Michael Seki, and Donald Hawn

Introduction

The American Samoa domestic longline fishery underwent extraordinary growth, particularly in the fleet composition of large vessels (>20 m in length), from 1999 to 2001. This growth fueled a concurrent fivefold increase in fishing effort and landings.

Prior to the sudden expansion, most longline fishing around American Samoa was accomplished through a fleet of smaller, ca. 10-m, open-decked catamarans known as *alia*. Post-expansion, the number of longline vessels has declined steadily but is still higher than in 1999. The fleet is now composed primarily of large vessels, increasing the number of hooks per set and sets per trip. This increase in both the number of hooks per set and in the number of sets per trip is the result not only of the increase in the size of the vessels but also in their ability to travel farther from port.

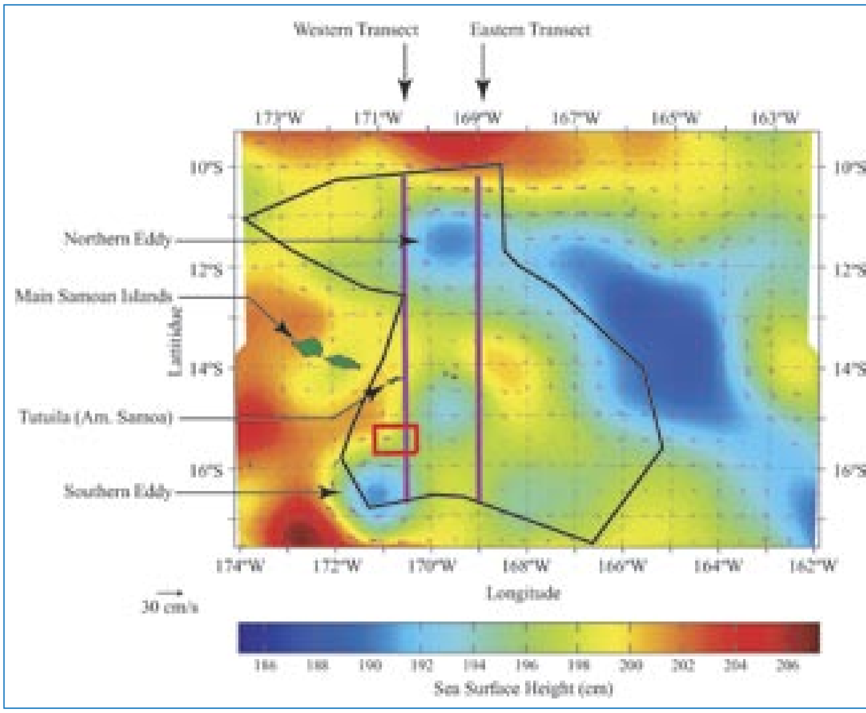

Figure 1. Map of the American Samoa EEZ (with irregular shaped borders) with mean sea surface heights for the week of March 7–13, 2004. The two vertical lines and the small box in the southwest part of the EEZ are the two meridional transects and Box 1 described in the text.

Current Concerns and Research

Concerns now abound that the expanded fleet is affecting the local resources of large pelagic fish. For example, the fishery's performance for albacore tuna—*Thunnus alalunga,* the target species of the longline fishery dominating the catch—in the American Samoa Exclusive Economic Zone (EEZ) peaked in 2001 with 24.17 fish per 1000 hooks and then steadily declined and reached a low of 12.82 fish per 1000 hooks in 2004.

However the performance of the fishery has started to recover during recent years. This has raised questions regarding the extent of the impact of the fishery in comparison with other effects—such as those of changing oceanographic conditions in the region.

To date there has been little oceanographic study of the pelagic habitat in the American Samoa region. Large-scale circulation patterns suggest that the American Samoa EEZ, where most of the fishing occurs, is heavily influenced by the meandering flow of the broad South Equatorial Current (SEC). Also the South Equatorial Counter Current (SECC) flows over the northern part of the EEZ, peaking in amplitude from March to April. Strong horizontal shear between the westward-flowing SEC and the eastward-flowing SECC results in barotropic instability and seasonally modulating mesoscale eddy kinetic-energy levels.

The presence of mesoscale eddies has been shown to be an important factor in fishery performance, leading to increased

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Pelagic Fisheries Research Program Newsletter
Volume 13, Number 1 **January–April 2008**

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catch per effort for albacore tuna. This increase is most likely from the increased biomass of tuna in the presence of eddies. Mesoscale eddies are known to concentrate large pelagic fish, such as tuna, presumably to feed on the larger aggregations of forage, such as micronekton.

Our current research is investigating the pelagic habitat and fishing grounds utilized by the American Samoa longline fishery. Efforts are underway 1) to understand the spatial and temporal occupation patterns and movements of large South Pacific albacore and 2) to examine the role of environmental changes in albacore and micronekton distribution as well as in longline performance and catch. Identifying oceanographic features of tuna habitat and understanding those characteristics that affect the spatial and temporal distribution of albacore will help in developing and maintaining sustainable fishing practices for this commercially important species.

Data and Methods

In situ shipboard conductivity-temperature-depth (CTD) surveys, together with satellite altimetry data, were used to assess the oceanographic characteristics of the fishing grounds. CTD casts were conducted from the National Oceanic and Atmospheric Administration (NOAA) vessel *Oscar Elton Sette* between March 3 and 13, 2004, along two meridional transect lines (Figure 1); the "western transect" and the "eastern transect," down to 1000 m depth. The CTD system used was equipped with dissolved-oxygen sensors and a fluorometer for in vivo chloropigment determinations.

Sea surface heights (SSH) were obtained from the Segment Sol multimissions d'ALTimétrie, d'Orbitographie et de localisation précise (Ssalto) program's AVISO TOPEX/POSEIDON—JASON-1 altimetry data product for the years 1996–2004 for the area of 172°W to 148°W, 30°S to 5°N. This data corresponds in time with the American Samoa longline fishery logbooks (see following) and in space to the fishing grounds. SSH are weekly averages gridded over 0.25° x 0.25° sea level anomalies to which the 1994 National Oceanographic Data Center (NODC) World Ocean Atlas Levitus long-term mean dynamic heights were added.

The American Samoa longline fishery performance for albacore was assessed using catch and hooks data from the fishery's mandatory federal logbook program (implemented in 1996). Only data from 2002 through early 2004 (the latter the extent of the data available at the time of analysis) were analyzed to limit any effects the change of composition of the fleet from pre- to post-expansion times.

Settling depths of longline gear were obtained using temperature and depth recorders (TDRs) attached to three sets deployed within "Box 1" (Red box in Figure 1). To study the depth distribution of albacore, six adult fish were equipped with pop-up archival tags between February 29 and March 2, 2004, within the area of Box 1. Temperature and depth records were grouped into 1-hr or 4-hr long, 50-m deep bins down to 1000 m. Data from two tagged albacore were analyzed—one with a sixteen-day record, the other with a six-day record; data from tags "surviving" less than two days were not used.

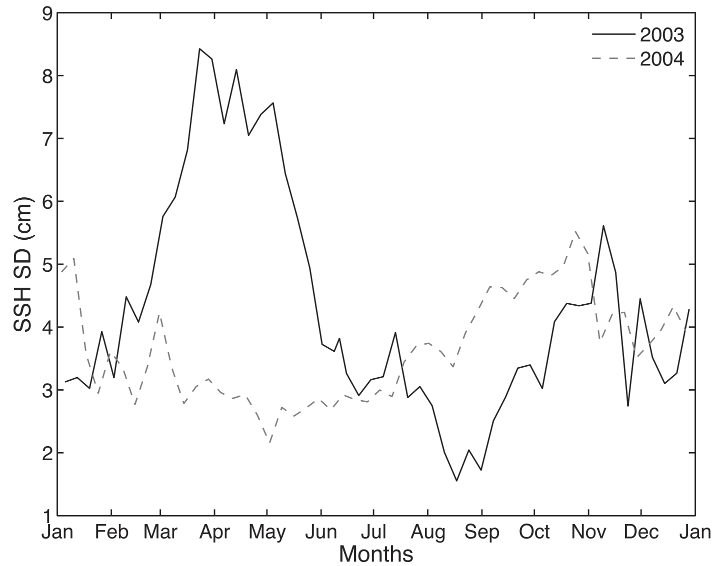

Figure 2. Weekly mean standard deviations of SSH within the EEZ for the years of 2003 (solid line) and 2004 (dashed line).

To examine the distribution and abundance of micronekton (primary forage for albacore) in situ acoustic backscatter data were collected on board the *Oscar Elton Sette* along the western and eastern transects between March 3 and 13, 2004. The *Oscar Elton Sette* is equipped with a hull-mounted split-beam Simrad EK60 echo-sounder system operating at 38 and 120 kHz frequencies, with approximate ranges of 800 and 200 m, respectively.

Raw voltage output from the echo-sounders were converted to mean volume backscattering strengths (S_v, in dB re 1 m^{-1}) then integrated over 50 m long and 5 m deep bins to obtain mean Nautical Area Scattering Coefficients (NASC, in m^2 nmi^{-2}) using Sonardata Echoview® software.

This study used NASC data as a proxy for relative biomass estimates since, assuming that the composition of scattering layers does not vary significantly, they are proportional to one other. Only the 38 kHz backscatter from the upper 500 m could be used quantitatively as data from below that depth were contaminated by noise.

Results and Discussion

Weekly SSH records show that the American Samoa fishing ground is a dynamic region with strong mesoscale eddy activity showing temporal variability on scales of less than one week.

Typically, relatively high SSH in the northern part of the EEZ identifies the SECC during the peak months of March and April. During this time the strength of eddy activity, measured as the standard deviation (SD) of SSH within the American Samoa EEZ, is higher than during the rest of the year (Figure 2, solid line). Besides the seasonal variability, the SECC and the resulting eddy activity in the EEZ show inter-annual changes. For example, during 2004 the SECC failed to intensify, resulting in a corresponding lack of a peak in eddy activity in the EEZ (Figure 2, dashed line).

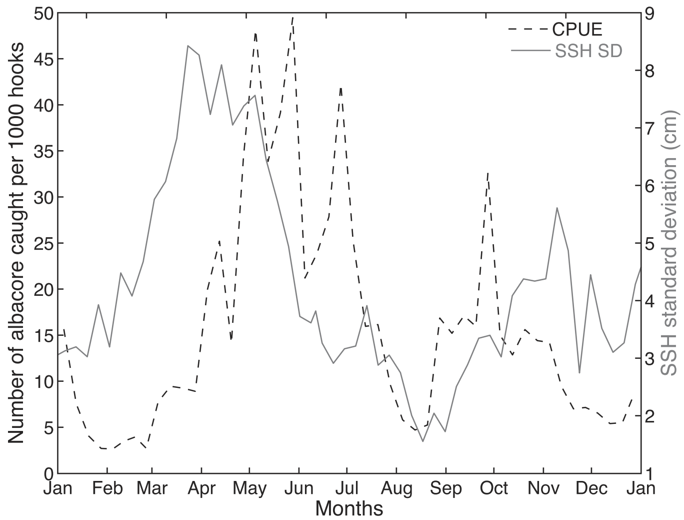

Figure 3. Weekly mean standard deviations of SSH and albacore CPUE within the EEZ for the year of 2003.

Interestingly, CTD records do not reflect the presence of the two cyclonic eddies during the in situ observations (Figure 1): one in the north between the eastern and western transects (the "northern eddy") and one in the south, west-southwest of the southern end of the western transect (the "southern eddy"). The lack of characteristic shallowing of the thermocline and lower sea-surface temperatures at the eddies is puzzling. However mid-ocean eddies, such as the eddies in this region, do not necessarily develop sea surface temperature signatures.

The CTD data do, however, reflect some larger scale trends. There is a shallowing of the thermocline from south to north, as well as a northwest decrease in near-surface salinity and dissolved oxygen between 0–1000 m, with a sharp boundary below 300–400 m. Chloropigment concentrations are highest at 100–150 m depth and show an increase toward the northwest.

These larger scale changes in water characteristics might reflect the differences in water masses carried by the SEC and SECC. As the SECC originates at the east of New Guinea and follows the South Pacific Convergence Zone southeast, it is expected to have high near-surface temperatures and low salinity, resulting in the low near-surface salinities in the northwest of the EEZ.

Longline albacore catch seems to be influenced by both the intra- and inter-annual variability in mesoscale eddy activity. On the seasonal scale, catch tend to be located at the eddy periphery, especially during times of peak eddy activity. Additionally albacore catch per unit of effort (CPUE—measured as number of albacore caught per 1000 hooks) show intra-annual variability with high CPUE from May through July relative to that from August through April (Figure 3). Further, during the May-July period, CPUE tend to be significantly higher in the northern half relative to the southern half of the American Samoa EEZ. This intra-annual variability in CPUE lags that of the SECC by about two months (Figure 3).

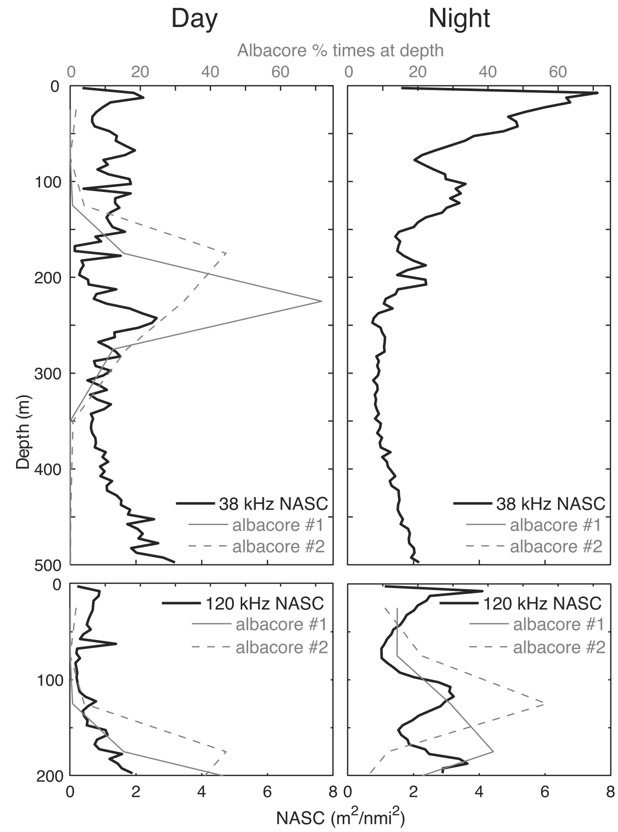

Figure 4. Percent time spent at depth by two tagged albacore (solid and dashed gray lines), with the horizontally averaged Nautical Area Scattering Coefficients (solid thick line) at 38 kHz (top) and at 120 kHz (bottom), during daytime (left) and nighttime (right).

Contrary to the years of 2002–2003, albacore catch and CPUE shows no seasonal peak in 2004, corresponding to the lack of seasonal intensification of the SECC. In fact, albacore catch (CPUE) dropped from 270 thousand (21 per 1000 hooks) to 130 thousand (13 per 1000 hooks) from 2002–2003 to 2004.

The most prominent feature of the acoustic backscatter is the diel change due to vertical migration of micronekton. The acoustic backscatter is strongest between 20–120 m during the nighttime and between 400–700 m during the day (Figure 4). Diel changes in the differences in backscatter between the two frequencies in the upper 200 m indicate that most of the migratory organisms are small fish, gelatinous organisms with gas inclusions, or possibly squid.

On the large scale, relative biomass increases from the south to north and from east to west at both frequencies; although a connection with cyclonic eddy edges could not be confirmed. This lack of influence of eddies could be due to the vertical migration of most micronektonic organisms to and from depths below the influence of eddies or because during the time of the survey eddy activity in the EEZ was low (Figure 2), resulting in no clear effect on micronekton biomass.

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Oceanographic Investigation (continued from page 7)

Spatial distribution of albacore does seem to be governed by the distribution of forage. The two longer-term tagged albacore spent most of their time between 150–250 m depth, coinciding with a thin, persistent scattering layer (Figure 4)—as well as the settling depth of the three longline sets on which tags were deployed. Differences in backscatter between the two frequencies indicate that this layer shows characteristics most consistent with higher abundance of crustaceans and cephalopods than fish relative to other depths, corresponding to South Pacific albacore's preferred diet in these waters. The South Pacific albacore's preferred diet is inferred from stomach samples taken in the vicinity of American Samoa.

Further, both temperatures and dissolved-oxygen levels, shown to be important factors for albacore distribution, are found to be within South Pacific albacore's preferred range from the surface down to 750 m within the entire EEZ, implying they are not limiting factors in either horizontal or vertical distribution. Albacore horizontal and vertical distribution has been found to be influenced by the availability of prey in the bordering French Polynesian EEZ.

Supporting this argument is the two-month lag found between the peak in eddy activity and that shown in albacore CPUE, which might indicate the time needed for the accumulation of micronekton in response to environmental factors.

While leaving many questions unanswered, this study provides strong support for the importance of the SECC to the performance of the local fishery for albacore, as well as essential information on albacore and micronekton movement patterns and distribution in the American Samoa EEZ. Although preliminary, the results presented here provide valuable information for directing future research on the oceanographic characterization of this economically important area. Additional details of this research may be found in our recently published article in *Fisheries Oceanography* 16:6, 555–572.

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