

GROUP 4: HIGHLY MIGRATORY FISHES, SEABIRDS AND MARINE MAMMALS

Seabirds reflect changes in ocean climate

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Seabirds spend most of their lives on the ocean but come to shore to raise their young. Most seabirds breed on island colonies. When birds are on the colony it is relatively easy for scientists to obtain rigorous quantitative information on their diet, reproduction and survival. The response of seabirds to variation in ocean climate will likely reflect species-specific traits that include body size, cost of foraging, potential foraging range, ability to dive, amount of 'spare' time in the daily budget, and ability to switch diet (Furness and Tasker 2000). The following example outlines some research on Triangle Island, British Columbia, Canada, examining time-series data on breeding seabirds during a period of extreme variation in ocean temperatures.

Background and natural history

British Columbia has major proportions of the world's populations of Cassin's Auklet and Rhinoceros Auklet, which breed on a few large colonies. Triangle Island (50°52'N, 129°05'W), an Ecological Reserve and internationally Important Bird Area (IBA), is the outermost of the Scott Island Group off the northern tip of Vancouver Island (Fig. 1). The island supports the world's largest population of Cassin's Auklet (*Ptychoramphus aleuticus*; 1.1 million breeders) and a large population of Rhinoceros Auklet (*Cerorhinca monocerata*; 82,000 breeders) in addition to significant populations of Tufted Puffin (*Fratercula cirrhata*; 52,000 breeders) and Common Murre (*Uria aalge*; 8,200 breeders) (Rodway 1991). The Cassin's Auklet is a small (190 g) planktivorous, burrow-nesting seabird which visits the colony only at night. Nestlings leave the burrow (fledge) between 40-60 d old. The Rhinoceros Auklet (*Cerorhinca monocerata*)

is a 550 g piscivorous, burrow-nesting species that only visits the colony at night. Nestlings are cared for from 45-60 d until fledging. The Tufted Puffin is a 750 g, piscivorous, burrow nester which visits the colony at multiple times throughout the day. Nestlings fledge at 40-50 d. The breeding population for Triangle Island is estimated to be 26,000 pairs (Rodway 1991). The Common Murre is a large (950 g), piscivorous, cliff nesting, diurnal species. Nestling development is semi-precocial and the chicks leave the colony with their fathers at age 20-25 d to complete the majority of development at sea.

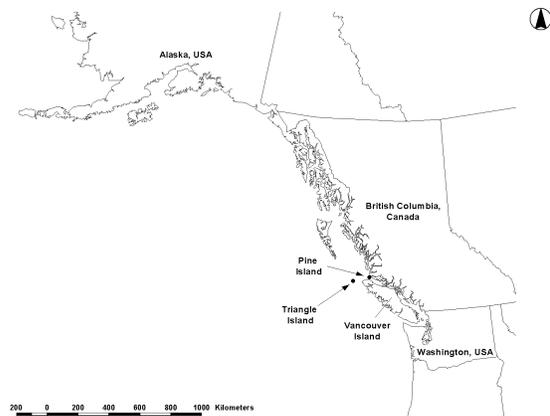


Fig. 1 Location of the seabird colony, Triangle Island, and Pine Island light station in British Columbia, Canada.

From 1989 – 1999, the Cassin's Auklet population size on Triangle Island has declined and breeding success was very poor in several years. To the south on the Farallon Islands in California, a 65% population decline of Cassin's Auklet from 1972-1997 has been linked to a long-term decline in zooplankton in the California Current marine

ecosystem (which stretches from California to Northern Vancouver Island). A decline in the world's largest population of Cassin's Auklet on Triangle Island may also be related to the long-term zooplankton changes in the California Current. However, in northern British Columbia, the Cassin's Auklets on Frederick Island (53°56'N, 133°11'W) show no sign of population decline and the birds have had consistently good breeding success in the 1990s, in marked contrast to the Triangle Island population. Populations of the fish eating Rhinoceros Auklets and Tufted Puffin are stable (1984-1999) and there is no indication of changes in the murre population on Triangle Island.

Time-series information

Seabirds are long-lived species so the research and monitoring must be conducted over appropriate durations to understand how populations change over time. The Pacific Seabird Group (led by Dr. Scott Hatch) in collaboration with the US Geological Survey is working to assemble an interactive database of time-series information for seabirds that is slated to be made available on the web. The database includes contributions from the PICES member nations (Canada, Japan, Russia and U.S.A.) as well as Mexico. An online data entry system is currently being developed so that researchers can easily update their time-series. The database contains information on population size, productivity, components of productivity, survival, reproductive chronology and food habits. Some of the time-series available from Triangle Island are described below, to illustrate the value of seabird time-series information for understanding changes in marine ecosystems (see Bertram *et al.* 2001 for details).

Triangle Island, the largest seabird colony in British Columbia, has the most extensive time-series data sets for the region, spanning three decades. Since 1994, researchers from Canadian Wildlife Service (CWS) and Simon Fraser University have been visiting the colony annually to collect information on breeding propensity, timing of breeding, hatch success, nestling growth and development, nestling diet, fledging success, adult survival and population trends. (Valuable data can be obtained at this site from surveys

shorter than 24 hr. The research focuses on the planktivorous Cassin's Auklet and the piscivorous Rhinoceros Auklet, Tufted Puffin and Common Murre.

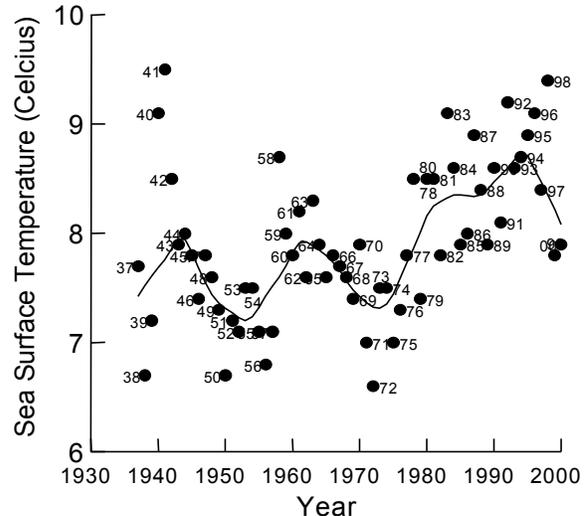


Fig. 2 Average sea surface temperature in April at Pine Is. light station, B.C., Canada.

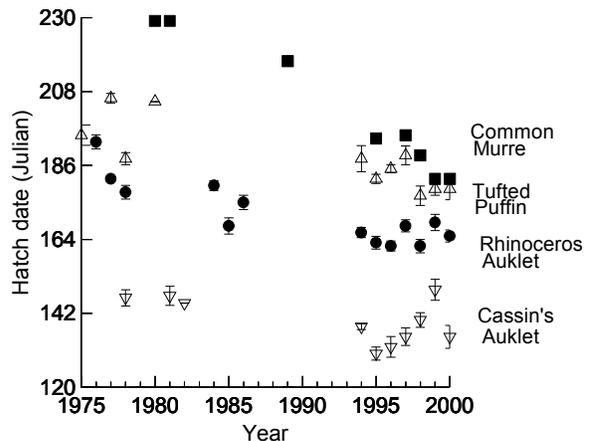


Fig. 3 Timing of breeding for seabirds on Triangle Island, B.C., Canada. Values are mean hatch dates (with 95% confidence intervals) for Cassin's Auklet Rhinoceros Auklet and Tufted Puffin. Values for Common Murre are dates when nestlings were first observed.

On the B.C. coast, the 1990s was the warmest decade of the century with some of the highest SSTs on record (Fig. 2). For the piscivores (Rhinoceros Auklet, Tufted Puffin and Common Murre), the timing of breeding in the 1990s and

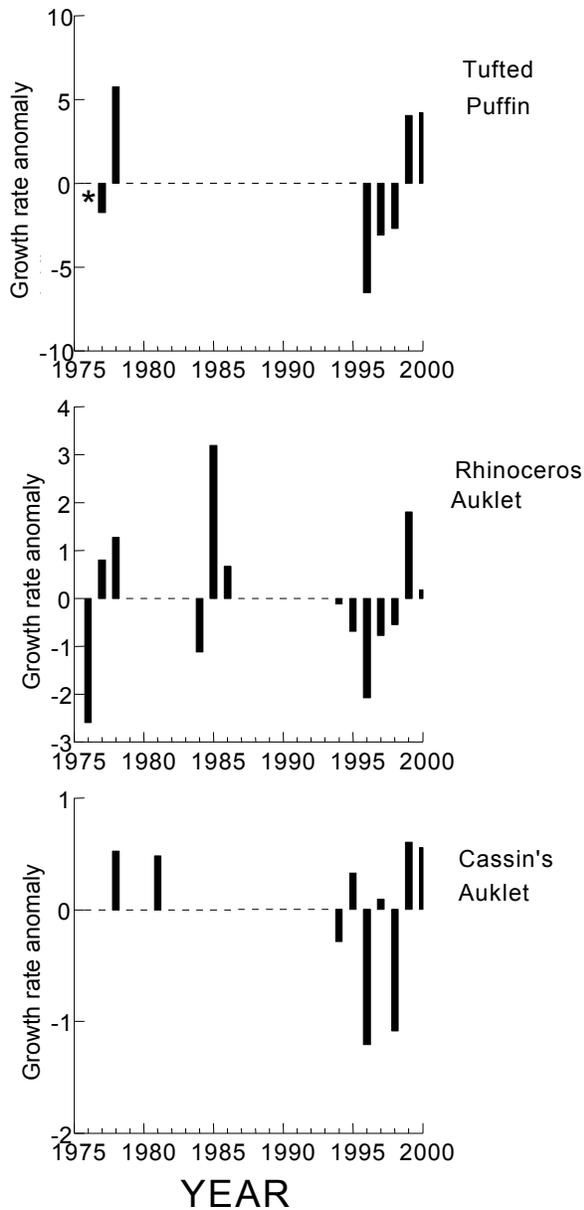


Fig. 4 Nestling growth rate anomalies (g/d) for Tufted Puffin, Rhinoceros Auklet and Cassin's Auklet on Triangle Island, B.C., Canada. Note that in 1976 breeding failure was observed for the Tufted Puffins because most eggs failed to hatch (marked by star).

2000 was significantly earlier than during the 1970s and 1980s (Fig. 3). For the planktivorous Cassin's Auklet, timing of breeding in the 1990s encompassed the entire range of values previously observed (Fig. 3). Nestling growth rates for Cassin's Auklet, Rhinoceros Auklet and Tufted Puffin tended to show poorer performance in the

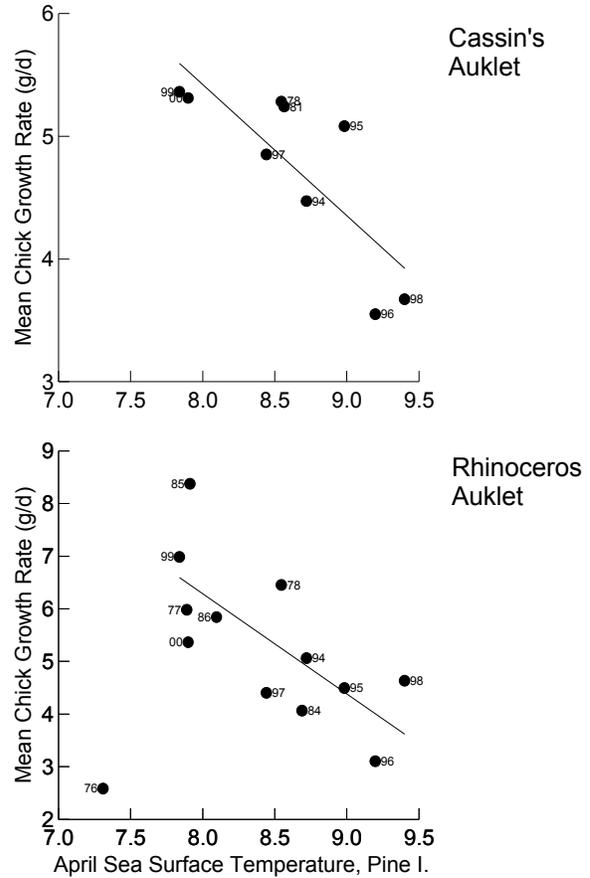


Fig. 5 Consequences of interannual variation in spring SST for Cassin's Auklet and Rhinoceros Auklet reproductive performance on Triangle Island, B.C., Canada. Growth rates of nestling Cassin's Auklet and Rhinoceros Auklets are generally lower when spring is early and sea surface temperatures are warm. Mortality from starvation is much more frequent when chick growth rates are low. The slopes of the lines are statistically significant for both the Cassin's Auklet ($y = 13.97 - 1.07x$; $F_{1,7} = 12.5$; $P = 0.009$) and the Rhinoceros Auklet (excluding 1976, $y = 21.53 - 1.91x$; $F_{1,10} = 11.2$; $P = 0.007$). Shown are mean annual population estimates of nestling growth rate in relation to the average SST in April at Pine Island light station.

1990s than in previous decades (Fig. 4). Between 1989 and 1999, the world's largest population of Cassin's Auklet on Triangle Island declined significantly (Bertram *et al.* 2000, CWS unpubl.). Note, too, that in the California Current ecosystem a 65% population decline of the planktivorous Cassin's Auklet on the Farallon Islands from 1972-

1997 (Nur *et al.* 1998) has been linked (Ainley *et al.* 1996) to a significant long-term decline in zooplankton production in the California Current system (Roemmich and McGowan 1995).

For Cassin's Auklet and Rhinoceros Auklet, warm waters in spring are associated with poor nestling growth (Fig. 5). The poor performance of the Cassin's Auklet during warm spring years likely reflects a temporal mismatch between the timing of availability of their main prey (*Neocalanus cristatus*) and the timing of breeding (Bertram *et al.* 2001). In warm spring years (e.g., 1996 and 1998) the zooplankton peak is early and poor nestling growth and large scale nestling mortality are observed for Cassin's Auklet. The mechanism linking poor nestling growth and warm SST is less clear for the piscivorous Rhinoceros Auklet, but may be related to temperature dependent recruitment to fish prey populations such as Pacific sand lance (*Ammodytes hexapterus*).

The focus here has been on a colony-based example data but time-series data on birds at sea can also reveal significant patterns related to climate variability. For example, declines in populations of seabirds wintering in the California Current ecosystem have been associated with the large-scale decline of zooplankton in that ecosystem (Veit *et al.* 1996).

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Assessment of feeding impact by higher trophic predators

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Okamura (2000) tried to develop an ECOPATH/ECOSIM model of the western North Pacific to elucidate the role of marine mammals and marine birds in the ecosystem. His attention was focused on two sub-regions: the Western Tropical Zone (WTZ) and the Kuroshio/Oyashio

Region (KR/OY) in the PICES area in which food consumption by sea birds and marine mammals was assessed by PICES Working Group 11. These two sub-regions were selected based on data availability and academic interests of many Japanese fisheries scientists. In the case where

toothed whales were removed from components in the western North Pacific model to give a high fishing rate, the biomasses of large squids and miscellaneous fishes in the ecosystem have increased two-fold at the end of the simulation but those of mesopelagics decreased by half. On the other hand, in the case where baleen whales, pinnipeds and sea birds were removed simultaneously from the ecosystem to give a high fishing rate, the remarkable change of biomass for various species was not observed. Furthermore, the author had made sensitivity test on the difference of the diet composition for respective whale groups. The change of the diet composition of the baleen whales had no big effect on the biomass trajectory, seemingly due to the small biomass of the baleen whales in this area. The

change of the diet composition of the toothed whales had big visible effect on biomass change for every group in the ecosystem. These results suggest the importance of the toothed whales in the ecosystem. Okamura and his colleagues are now trying to construct the revised western North Pacific ECOPATH/ECOSIM model that incorporates more detailed information about biomass and diet composition for fishes.

Reference

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Data summary: Impact of climate variability on observation and prediction of ecosystem and biodiversity changes in the North Pacific

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The Exxon Valdez Trustee Council (EVOS) funds data collection, analysis and modeling by scientists at government, university and private institutions. The data for each project are submitted in the form of final reports, however, publication in peer-reviewed journals is strongly encouraged. Original data are held by the authors, and may be replicated in the final report. Formats are paper, MS-Word, Adobe Acrobat (pdf), and original software provided by authors.

Types of data

Observations and analyses from marine areas of the northern Gulf of Alaska include those of birds, fishes, shellfishes and mammals, physical, chemical, biological, geological and atmospheric data. The following parameters are considered: abundances, age structure, distributions, physiology, growth, survival, energetics, trophic level, contaminant burdens, multiple life cycle stages, macro- and micro-invertebrates and vertebrates

and marine plants, air and water temperature, salinity, currents, wind, and bathymetry.

Prominent higher trophic level species are: pink salmon (embryos, adults), mussels, clams, sea otters, harbor seals, kittiwakes, murre, pigeon guillemot, and harlequin duck.

Time-series

Data collected by EVOS do not presently exceed 11 years (1989–present), however, for some oceanographic and biological variables, analyses include comparisons of EVOS data to historical data sets. Since observations are available on hundreds of species and several types of physical phenomena for varying lengths of time, locating time-series of interest requires the following:

1. Searching the file “EVOS Final Report List & Abstracts.doc” by keywords for the project title and number of interest;

2. Locating the "Project data field" following the abstract for projects of interest;
3. Locating data by consulting the Adobe Acrobat version of the Final Report at "<http://dtlcrepository.downtownlegal.com/ARLIS/PDF/>" or from the peer-reviewed publication to be found by searching the bibliography "EVOS TC Supported publications 020901.pdx";
4. Data not available from the Final Report or journal may be obtained from the author and agency, or often from the U.S. National Technical Information Service (NTIS), as indicated in the file "EVOS Final Report List & Abstracts.doc".

Models

1. Numerical simulation of the seasonal ocean circulation patterns and thermohaline structure of Prince William Sound based on the Princeton 3-D ocean circulation model (Wang and Mooers 1996; Wang *et al.* 1999).
2. A mass-balanced ECOPATH model of trophic flows in Prince William Sound: decompartmentalizing ecosystem knowledge (Okey and Pauly 1999).
3. Plankton dynamics: observed and modeled responses to physical factors in Prince William Sound, Alaska (Eslinger *et al.* in press).
4. Herring over-wintering survival model in Prince William Sound (Brown *et al.* unpubl.).

Metadata

1. EVOS GEM GOA database: descriptions and geographic coordinates of 280 active and

historic data gathering projects in the Gulf of Alaska and adjacent waters by all U.S. and some Canadian entities. Satellite observing programs are included. Format: Summaries Excel and FileMaker Pro.

2. GIS: geographic locations with abstract of project's metadata for those with multiple sampling sites. Format: ArcView shape files.

Electronic bibliographies

1. TC Bibliography (file name: EVOS TC Supported publications 020901.pdx): work supported by EVOS includes 404 peer-reviewed journal citations, theses and dissertations, some with abstracts for marine biology, geophysics and numerical and statistical models. Search engine is provided. Format: ProCite (*.pdx).
2. GEM Cites Bibliography (file name: EVOS Gemcites 030101.pdx): 1,011 peer reviewed works and authoritative agency data reports cited in the GEM synthesis document or current synthesis articles on marine biology, geophysics, astrophysics, and numerical and statistical models. Search engine is provided. Format: ProCite (*.pdx).
3. EVOS Final Report List & Abstracts.doc – starts with a list of all Final Reports by number, author, title, agency and NTIS number if applicable. Searchable by key words or phrases. Format: MS-Word 2000 (*.doc).
4. EVOS Final Reports reviewed and accepted as of September 30, 2000, are available electronically in Adobe Acrobat (*.pdf) on two CD's and on web at "<http://dtlcrepository.downtownlegal.com/ARLIS/PDF/>".

Yellowfin, bigeye, skipjack, bluefin, and albacore tunas in the Eastern Pacific Ocean

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The time-series described are for the eastern Pacific Ocean (EPO), currently defined as the area

bounded by the coastline of North, Central, and South America, 40°N, 150°W, and 40°S. The

IATTC (Inter-American Tropical Tuna Commission) staff maintains records for most of the vessels which fish at the surface for yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bigeye tuna (*Thunnus obesus*), or Pacific bluefin tuna (*T. orientalis*) in the EPO. Records are not maintained for sport-fishing vessels and small craft, such as canoes and launches.

The IATTC maintains field offices in Manta and Playas, Ecuador; Ensenada and Mazatlán,

Mexico; Panama, Republic of Panama; Mayaguez, Puerto Rico; U.S.A.; and Cumaná, Venezuela. The scientists and technicians stationed at these offices collect landings data, abstract the logbooks of tuna vessels to obtain catch and effort data, measure fish and collect other biological data. Most of the data analyses are conducted by the permanent, internationally-recruited research and support staff at the IATTC's headquarters in La Jolla, California, U.S.A. The time-series presented in this report are summarized in Table 1.

Table 1 Data time-series summarized in this report. PS = purse seine, LL = longline, BB = baitboat.

Time Series	Figure number	Beginning year	Gear	EPO Sampling Locations	Estimate interval	Type of analysis
Yellowfin recruitment	Figure 7	1975 ¹	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. yn. Model (A-SCALA)
Yellowfin biomass	Figure 8	1975 ¹	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Yellowfin average weight	Figures 9 & 10	1975 ¹	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye recruitment	Figure 12	1975 ¹	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye biomass	Figure 13	1975 ¹	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye average weight	Figure 14	1975 ¹	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Skipjack ²	–	–	PS-2 set types BB	Figure 15 (1984-1998)	–	–
Bluefin CPUEs	Figures 18 & 19	1960	EPO: PS WPO: trolling, PS, traps, gillnets, LL	Figure 16 (1970-1989) Figure 17 (1972-1976)	Yearly	Habitat index, Regression Trees
Albacore ³	–	–	LL, trolling, BB	Figures 19, 20 (1999; 1952-1976)	–	–

¹ Prior to 1975 the purse-seine fishery had not yet expanded its operations offshore.

² The IATTC is working during 2001 on improved analyses of skipjack tuna using the same length-based age-structured model approach used for yellowfin and bigeye tunas in the EPO. Therefore, time-series estimates of recruitment, biomass, and average weights are not presented in this report.

³ Time-series of recruitment, biomass, and average weights are not available for albacore in the North Pacific Ocean.

Yellowfin tuna

The average annual distributions of the logged catches of yellowfin tuna by purse seiners in the EPO during 1984-1998 are shown in Figure 6. Most of these catches are from tropical and subtropical regions of the EPO. The annual distributions of catches have changed over the historical evolution of the fishery and are described by Bayliff (2001a). Prior to the mid-1950s, the eastern Pacific fishery for yellowfin took place mostly within 250 miles of the mainland, principally by baitboats. In the early 1960s, purse-seining became the predominant fishing method. During the mid-1960s the purse-seine fishery began to expand its operations further offshore, and by the mid-1970s vessels were fishing as far west as 150°W. During 1975 through 1998, the majority of yellowfin catch was taken by purse-seine sets on yellowfin associated with dolphins and by purse-seine sets on yellowfin in unassociated schools (Maunder and Watters 2001).

The most recent stock assessment of yellowfin tuna in the EPO is presented by Maunder and Watters (2001). An age-structured population dynamics model and information contained in catch, effort, and size-composition data are used to assess the status of the yellowfin tuna stock in the EPO. The stock assessment model, termed an age-structured statistical catch-at-length analysis (A-SCALA), is based on the method described by Fournier *et al.* (1998). The assessment model uses quarterly time steps to describe the population dynamics. The A-SCALA method recognizes that there is temporal variation in recruitment, that the environment may influence both recruitment and the efficiencies of different fishing gears, and that different fishing methods usually catch fish of different ages. The model is described in detail by Maunder and Watters (2000).

It is assumed that yellowfin tuna can be recruited to the fishable population during every quarter of the year. The most-recent stock assessment of yellowfin makes no strong assumptions about the relationship between adult biomass (or abundance) and recruitment. The estimated time series of yellowfin recruitment is shown in Figure 7 (Maunder and Watters 2001). The estimates are

scaled so that the average recruitment is equal to 1.0, which is 39,257,074 fish per quarter. The recruitment of yellowfin tuna to the fisheries in the EPO is variable, and appears to be related to sea-surface temperatures (SSTs). The levels of recruitment to the fishery, at the age of 6 months,

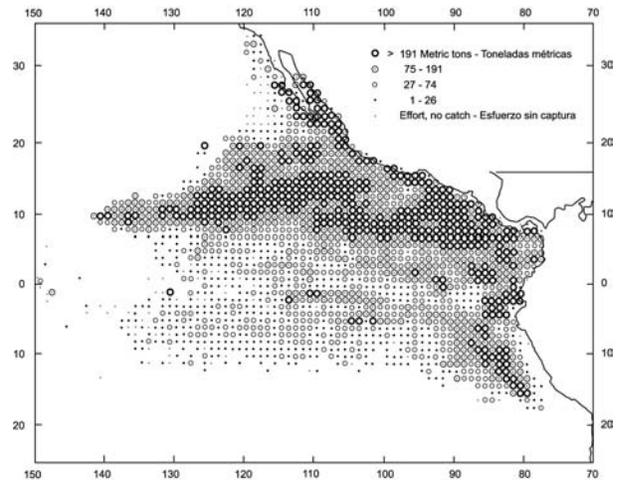


Fig. 6 Average annual catches of yellowfin tuna in the EPO during 1984-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

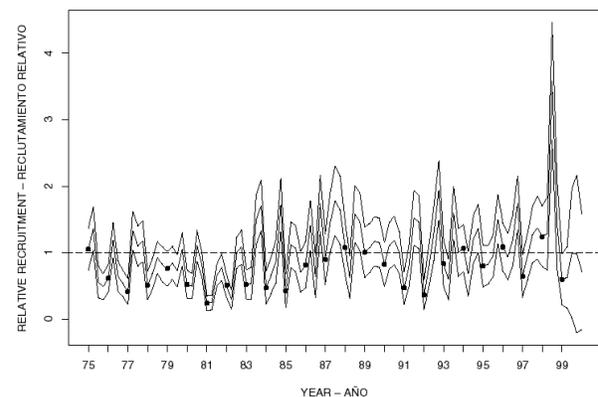


Fig. 7 Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95-percent confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year (from Maunder and Watters 2001).

are positively correlated with the SST anomalies at the time of spawning 6 months earlier. However, SST does not explain all the variation in recruitment, and it is possible that other oceanographic variables influence the recruitment. The IATTC staff intends to consider other environmental indices as candidates for explaining the variation in recruitment.

One hypothesis is that the yellowfin population has experienced two different recruitment regimes (1975-1984 and 1985-1999), the second being higher than the first. These two regimes in recruitment are also correlated with regimes in the SSTs. This change in recruitment levels produces a similar change in biomass (Fig. 8). The analysis indicates that a very strong cohort entered the fishery in 1998 and that this cohort increased the spawning biomass ratio (the ratio of spawning biomass during a period of harvest to the spawning biomass which might accumulate in the absence of fishing, SBR) and catches during 1999. There is also an indication that most recent recruitments are low, which may lead to lower SBRs and catches. The lower SSTs may also indicate that the most recent recruitments will prove to be lower. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

The trends in the biomass of yellowfin (fish that are at least one and a half years old) in the EPO are shown in Figure 8 (Maunder and Watters 2001). During 1975-1983 the biomass of yellowfin decreased from about 315,500 to 151,000 mt, caused by high levels of catch and less-than-average recruitment (assuming an overall average and not two regimes). It then increased

rapidly during 1983-1985, and reached about 351,000 mt in 1985. This increase in biomass was caused by an increase in average recruitment (Fig. 7) and an increase in the average size of the fish caught. Since 1985 the biomass has been relatively constant. Increased fishing pressure prevented the biomass from increasing further during the 1986-1990 period.

The spawning biomass is defined as the total weight of mature female yellowfin. The estimated trend in spawning biomass is shown in Figure 8. The spawning biomass has generally followed a trend similar to that for biomass, described in the previous paragraph.

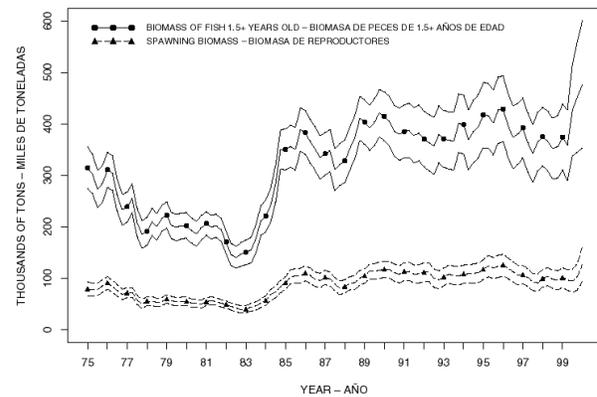


Fig. 8 Estimated biomass and spawning biomass of yellowfin tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95-percent confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year (from Maunder and Watters 2001).

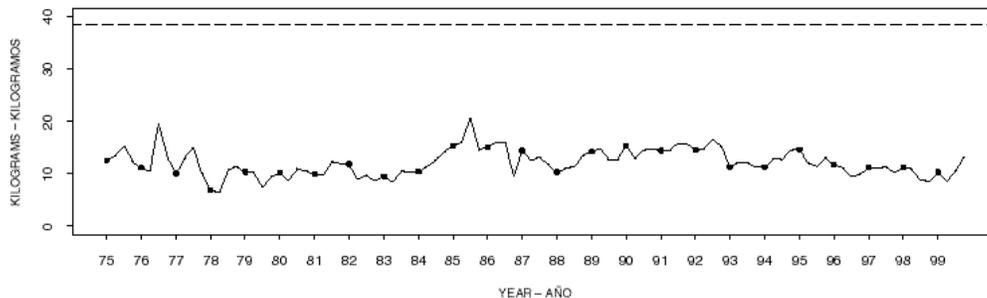


Fig. 9 Estimates of overall average weights of yellowfin tuna in the EPO. The critical weight is drawn as the horizontal dashed line (from Maunder and Watters 2001).

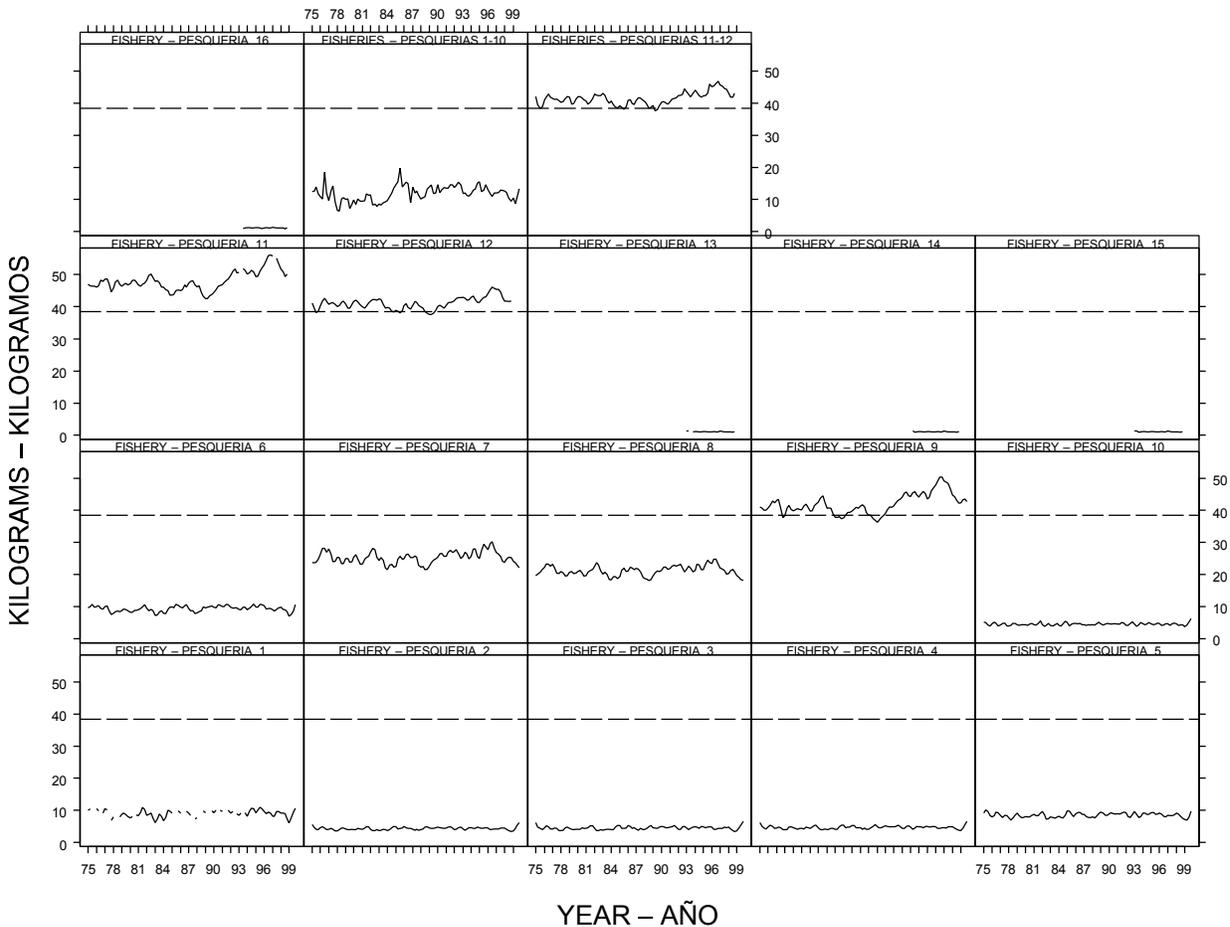


Fig. 10 Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time-series for “Fisheries 1-10” is an average of Fisheries 1 through 10, and the time-series for “Fisheries 8-9” is an average of Fisheries 8 and 9. The dashed line identifies the critical weight (from Maunder and Watters 2001).

The overall average weights of the yellowfin tuna caught in the EPO predicted by Maunder and Watters (2001) have been consistently around 10 kg for most of the period from 1975 to 1999 (Fig. 9), but have differed considerably among fisheries (Fig. 10). Sixteen fisheries were defined for the stock assessment of yellowfin tuna. These fisheries were defined on the basis of gear type (purse seine, baitboat, and longline), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), and IATTC length-frequency sampling area or latitude. The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Fig. 10). The lowest average weights (about 1 kg) are produced by the discard fisheries (Fisheries 13-16), followed by the baitboat fishery (Fishery 10; about 4-5 kg), the

floating-object fisheries (about 4-5 kg for Fisheries 2-4 and 10 kg for Fishery 1), the unassociated fisheries (Fisheries 5 and 6; about 8-10 kg), the northern and coastal dolphin-associated fisheries (Fisheries 7 and 8; about 20-30 kg), and the southern dolphin-associated fishery and the longline fisheries (Fisheries 9, 11, and 12; each about 40-50 kg).

Bigeye tuna

The average annual distributions of the logged catches of bigeye tuna by purse seiners in the EPO during 1994-1998 are shown in Figure 11. Most of these catches are from tropical and subtropical regions of the EPO, and there are substantial catches from south of the equator.

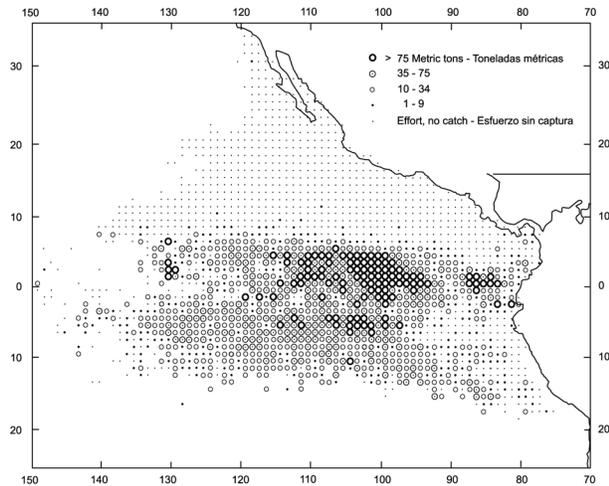


Fig. 11 Average annual catches of bigeye tuna in the EPO during 1994-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

The most recent stock assessment of bigeye tuna in the EPO is presented by Maunder and Watters (2001). There have been important changes in the amount of fishing mortality exerted by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 14 quarters old was negligible until about 1994. Since 1993, the expansion of fisheries that catch bigeye in association with floating objects and the widespread use of fish-aggregating devices (FADs) has, on average, caused the fishing mortality on these young fish to increase. Purse-seine sets on floating objects select mostly young bigeye that are about 5 to 16 quarters old. It is assumed that bigeye from about 2 to 5 quarters old are discarded while the catch taken around floating objects is sorted on board the vessels. Purse-seine sets on unassociated schools of tuna select bigeye that span a wide range of ages, and since 1990, fish that were about 7 to 20 quarters old were most selected by this mode of fishing. In the area north of 15°N, the longline fleet selects bigeye that are about 10 to 26 quarters old; south of this parallel, bigeye become relatively vulnerable to longline fishing after they are about 17 quarters old. The southern longline fishery typically selects bigeye that are older than those selected by any of the other fisheries operating in the EPO. The catchability of bigeye by purse-seine vessels has changed over time, and these changes have been caused mostly by random events that affect the

relationship between fishing effort and fishing mortality.

An age-structured population dynamics model and information contained in catch, effort, and size-composition data are used to assess the status of the bigeye tuna stock in the EPO (Watters and Maunder 2001). The stock assessment model, termed A-SCALA, is described briefly in the section on yellowfin tuna (above) and in detail by Maunder and Watters (2000).

It is assumed that bigeye tuna can be recruited to the fishable population during every quarter of the year. The most-recent stock assessment of bigeye makes no assumptions about the relationship between adult biomass (or abundance) and recruitment. The estimated time-series of bigeye recruitment is shown in Figure 12 (Watters and Maunder 2001). The estimates are scaled so that the average recruitment is equal to 1.0, which is 6,605,204 fish. Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment cannot currently be identified. The abundance of bigeye recruited to the fisheries in the EPO appears to be unrelated to SST anomalies at the time when these fish were assumed to have hatched. It is, however, possible that other oceanographic variables influence the recruitment, and the IATTC staff intends to consider other environmental indices as candidates for explaining the variation in recruitment. This will include offsetting the environmental index by one quarter (rather than two), to see whether recruitment is related to the environmental conditions during the early-juvenile phase (rather than the larval phase). Over the range of spawning biomasses estimated by the A-SCALA method, the abundance of bigeye recruited to the fishery also appears to be unrelated to the biomass of adult females present at the time of hatching.

Extremely large numbers of bigeye tuna are estimated to have been recruited to the fisheries in the EPO during 1997 and the first quarter of 1998. These recruitments were about 1.7 to 3.5 times the estimated level of average recruitment. Recruitment was estimated to be above average during most of 1995-1997, but below average during most of 1983-1991 and since the second quarter of 1998.

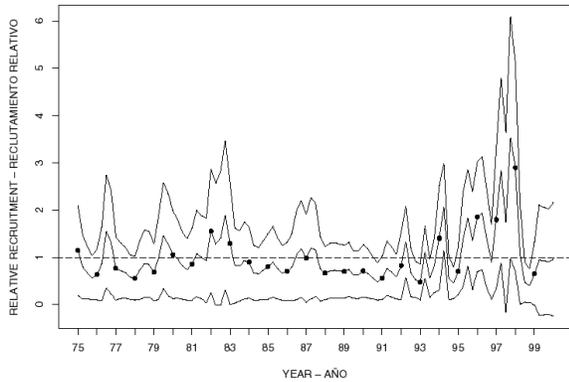


Fig. 12 Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95-percent confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year (from Watters and Maunder 2001).

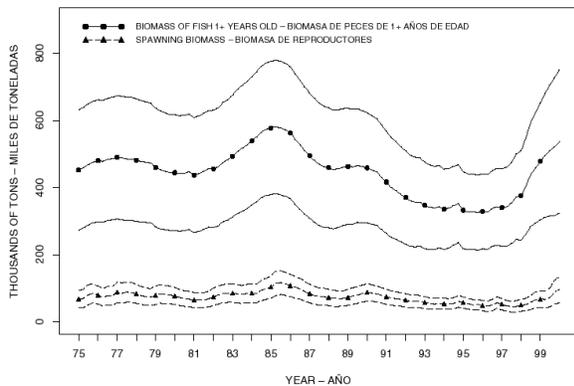


Fig. 13 Estimated biomass and spawning biomass (females that are at least 3 years old) of bigeye tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95 percent-confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year (from Watters and Maunder 2001).

Trends in the biomass of bigeye tuna in the EPO are shown in Figure 13 (Watters and Maunder 2001). During 1975-1980, the biomass of bigeye that were 1+ year-old is estimated to have been

relatively stable, at a level of about 468,000 mt. The biomass of this age group increased steadily during 1981-1984, and reached a historic high of about 581,000 mt during the second quarter of 1985. It then decreased, and reached a historic low of about 326,000 mt during the fourth quarter of 1995. Following this, the assessment model indicates a steady increase in the biomass of 1+ year-olds, to a level of about 538,000 mt by the beginning of 2000.

The estimated trend in spawning biomass is shown in Figure 13. The spawners are assumed to be females that are at least 3 years old. The spawning biomass has generally followed a trend similar to that for the biomass of 1+ year-olds, but there are slight differences in the timing of the highest and lowest estimates of spawning biomass because the spawners are relatively old.

Given the amount of uncertainty in both the estimates of biomass and the estimates of recruitment, it is difficult to determine whether, in the EPO, trends in the biomass of bigeye have been influenced more by variation in fishing mortality or by variation in recruitment. Nevertheless, the simulation exercises by Watters and Maunder (2001) make it apparent that fishing has reduced the total biomass of bigeye present in the EPO.

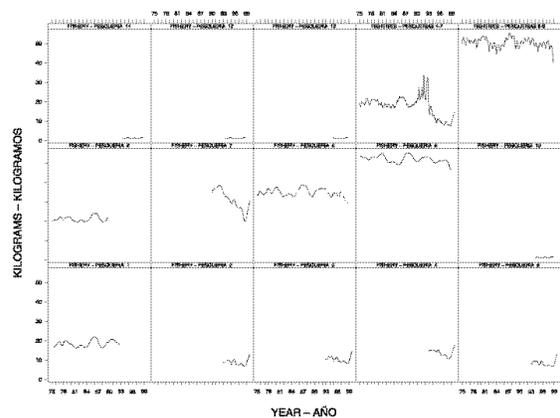


Fig. 14 Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time-series for “Fisheries 1-7” is an average of Fisheries 1 through 7, and the time-series for “Fisheries 8-9” is an average of Fisheries 8 and 9 (from Watters and Maunder 2001).

There have been important changes in the overall average weights of bigeye tuna caught by the surface fleet in the EPO predicted by Watters and Maunder (2001), due to changes in fishing mortality by different gears and purse-seine set types. These changes are illustrated in Figure 14. Thirteen fisheries were defined for the stock assessment of bigeye tuna. These fisheries were defined on the basis of gear type (purse seine, baitboat, and longline), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), time period, and IATTC length-frequency sampling area or latitude. Prior to 1993, the average weight of bigeye caught in association with floating objects was about 18 kg (Fig. 14, Fishery 1). During 1993-1998, the average weight of bigeye caught in purse-seine sets on floating objects declined, but larger fish were caught by these fisheries during 1999 (Fig. 14, Fisheries 2-5). Prior to 1990, the average weight of bigeye caught in unassociated schools was stable at about 21 kg (Fig. 14, Fishery 6), but, since 1990, the average weight of bigeye in the catch taken in unassociated schools has varied between about 20 and 35 kg, with an average of about 31 kg (Fig. 14, Fishery 7). The average weight of bigeye caught in unassociated schools increased during 1999. The average weight of bigeye caught by the combined surface fleet, not including the discard fisheries, during 1975-1999 was about 18 kg (Fig. 14, Fisheries 1-7). The assessment model currently treats the increase in average weight of bigeye caught by the surface fleet during 1999 as evidence of low recruitment from the latter half of 1998 through 1999 (Fig. 12), but it is also possible that the surface fleet has become capable of catching greater proportions of larger bigeye. The average weights of bigeye tuna taken by longliners operating in the EPO have remained relatively stable at around 50 kg (Fig. 14, Fisheries 8 and 9).

Skipjack tuna

The status of skipjack tuna in the EPO is summarized by Anonymous (2001b). Skipjack are fished in the EPO by purse seiners (in schools associated with floating objects and in unassociated schools) and by baitboats. The average annual distributions of the logged catches of skipjack tuna by purse seiners in the EPO during 1984-1998 are shown in Figure 15. Most

of the catches are made between northern Baja California and southern Peru, but the catches are relatively low off southern Mexico. The fishery extends westward to about 140°W in equatorial waters. Skipjack tagged in the EPO have been recaptured in the central and western Pacific Ocean, but no skipjack tagged in the central or western Pacific Ocean have been recaptured in the EPO.

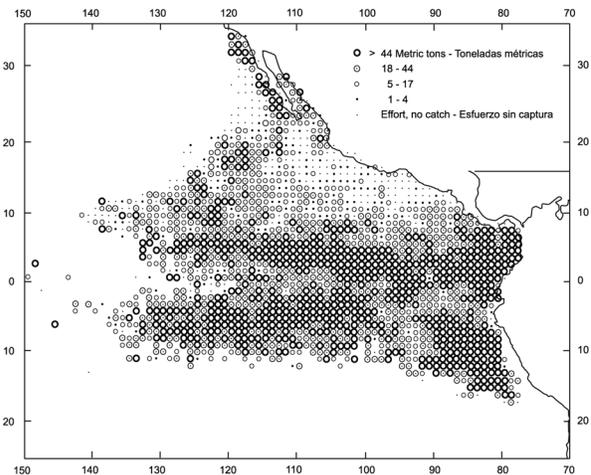


Fig. 15 Average annual catches of skipjack tuna in the EPO during 1984-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

The catches per unit of effort of skipjack by commercial fishing gear in the EPO are positively correlated with the sea-surface temperatures in the central Pacific 18 months previously (Anonymous 2001b). The catches of skipjack by surface gear tend to be reduced during El Niño episodes, however, and it is hypothesized that during such times the depth of the thermocline increases, so that the fish spend less time at the surface than during anti-El Niño years.

There are two principal hypotheses for the stock structure of skipjack in the Pacific Ocean (Anonymous 2001b). The separate-subpopulation hypothesis states that there are two or more genetically-distinct subpopulations of skipjack in the Pacific Ocean, and the clinal hypothesis states that separate subpopulations of skipjack do not exist in the Pacific Ocean, but that there is isolation by distance, i.e. the probability of any two fish interbreeding is an inverse function of

their distance from one another. The available data do not favor either the separate-subpopulation or the clinal hypothesis. It is reasonably certain that skipjack are underfished in the EPO (Anonymous 2001b). This situation could change, however, so it is important to learn more about this species and its relationships with the environment.

Time series of skipjack recruitment, biomass, and average weights are not presented here because the IATTC is working during 2001 on improved analyses of skipjack tuna data using the same length-based, age-structured model approach used for yellowfin and bigeye tunas in the EPO. Indices of abundance, however, are presented in Anonymous (2000a: Figure 51).

Pacific bluefin tuna

The status of Pacific bluefin tuna in the Pacific Ocean is summarized by Bayliff (2001b). Most of the catches of bluefin in the EPO are taken by purse seiners. The annual distributions of purse-seine catches of bluefin in the EPO during 1970-1989 are shown in Figure 16 (from Bayliff 1994). Nearly all of the purse-seine catch is made west of Baja California and California, within about 100 nautical miles of the coast, between about 23°N and 33°N. Lesser amounts of bluefin are caught by recreational, gillnet, and longline gear. Bluefin have been caught during every month of the year, but most of the fish are taken from May to October.

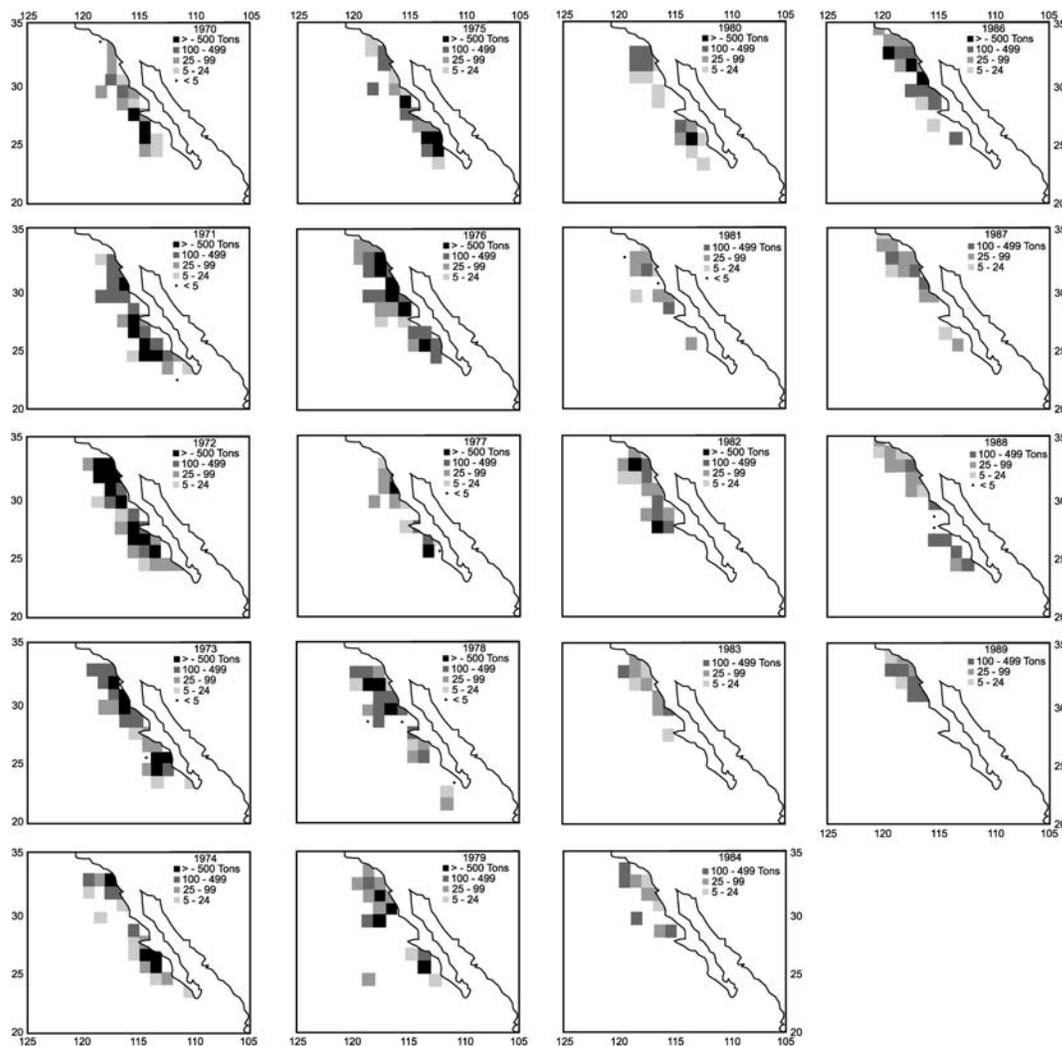


Fig. 16 Annual distributions of Pacific bluefin tuna catches in the eastern Pacific Ocean, 1970-1989 (from Bayliff 1994).

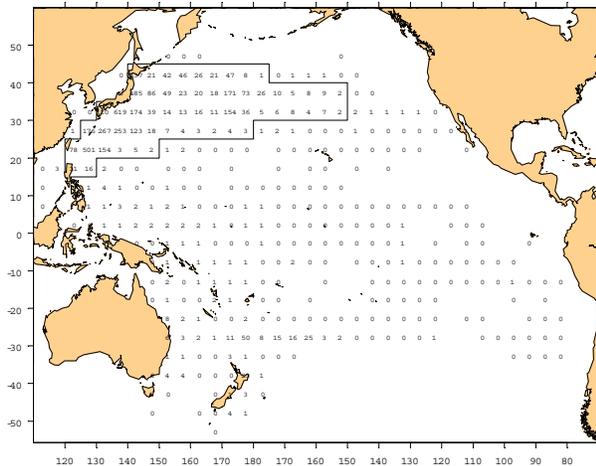


Fig. 17 5° latitude by 5° longitude quadrangles in which PBT were captured by the Japanese longline fleet during January 1952 – December 1997 (from Watters 1999). The numbers indicate the total number of PBT (100s) removed from each quadrangle during this period (zeros indicate catches of less than 51 fish). The quadrangles inside the polygon extending from Japan to 150°W constitute the core area defined by Tomlinson (1996).

Bluefin are exploited by various gears in the western Pacific Ocean (WPO) from Taiwan to Hokkaido (Bayliff 2001b). Age-0 fish about 15 to 30 cm in length are caught by trolling during July-October south of Shikoku Island and south of Shizuoka Prefecture. During November-April age-0 fish about 35 to 60 cm in length are taken by trolling south and west of Kyushu Island. Age-1 and older fish are caught by purse seining, mostly during May-September between about 30-42°N and 140-152°E. Bluefin of various sizes are also caught by traps, gillnets, and other gear, especially in the Sea of Japan. Bluefin are also caught near the southeastern coast of Japan by longlining.

The high-seas longline fisheries are directed mainly at tropical tunas, albacore, and billfishes, but some Pacific bluefin are caught by these fisheries. Catch distributions of bluefin by Japanese longliners during 1952-1997 in the Pacific Ocean are shown in Figure 17 (from Watters 1999). Small amounts of Pacific bluefin are also caught by Japanese pole-and-line vessels on the high seas.

Bluefin are most often found in the EPO in waters where the sea-surface temperatures (SSTs) are between 17 and 23°C (Bayliff 2001b). Fish 15 to 31 cm in length are found in the WPO in waters where the SSTs are between 24 and 29°C. Conditions in the WPO probably influence the portions of the juvenile fish there that move to the EPO, and also the timing of these movements. Likewise, conditions in the EPO probably influence the timing of the return of the juvenile fish to the WPO.

Various indices of abundance of Pacific bluefin in the EPO have been calculated, but none of these is entirely satisfactory. The IATTC has calculated “habitat” indices for the EPO routinely for several years. Since Bell (1963) had demonstrated that bluefin are most often found in waters where the SSTs are between 17 and 23°C, Bayliff (1996) considered the 1-degree areas north of 23°N and west of California and Baja California in which the SSTs were in that range during May through October to be “bluefin habitat.” He then divided the catches of bluefin in those 1-degree areas during each year by the corresponding numbers of unstandardized days of fishing effort to obtain CPUEs of bluefin (Fig. 18). Indices of abundance of bluefin for the WPO were prepared by Watters (1999) of the IATTC and by scientists from other nations. Watters’ time-series of abundance indices for the “core area” (Fig. 17) in the WPO for the Japanese longline fishery are shown in Figure 19.

The National Research Institute of Far Seas Fisheries, Japan, has been tagging Pacific bluefin tuna with archival tags to study the relationships between their movements and the physical environment (Anonymous 1999, Anonymous 2000b). Tsuji *et al.* (1999) reported the first recapture of a Pacific bluefin tuna that made a trans-Pacific migration while carrying an archival tag.

There was general agreement at a working group meeting on bluefin in December 2000, to start the process of developing a Pacific-wide assessment of bluefin tuna using the same length-based age-structured model approach used for yellowfin and bigeye tunas in the EPO (Anonymous 2000b).

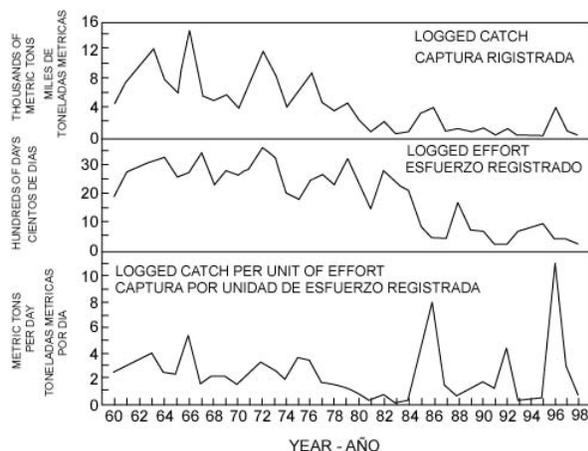


Fig. 18 Catch, effort, and catch-per-unit of effort data for the surface fishery for bluefin in the EPO, as determined by the habitat index method. The data for 1998 are preliminary (from Bayliff 2001b).

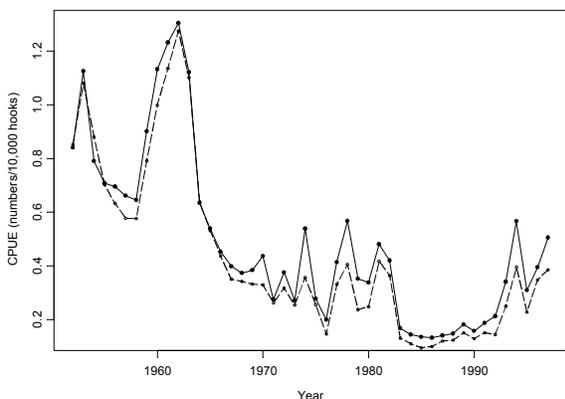


Fig. 19 Time-series of regional abundance indices for the entire PBT core area. The trend with a dashed line and open circles is the time series estimated from the safe abundance indices. The trend with a solid line and filled circles is the time series estimated from pooling the safe and the extrapolated abundance indices (see Watters 1999 for details).

Albacore tuna

The status of albacore tuna in the Pacific Ocean is summarized by Anonymous (2001a). There are two stocks of albacore in the Pacific Ocean, one occurring in the northern hemisphere and the other in the southern hemisphere. In the North Pacific, the adults live mostly in the Kuroshio Current, the North Pacific Transition Zone, and the California

Current, but spawning occurs in tropical and subtropical waters.

Albacore are caught by longliners in most of the North Pacific, but not often between about 10°N and 5°S, by trollers in the eastern and central North Pacific, and by baitboats in the western North Pacific (Anonymous 2001a). Albacore are caught by fisheries from several nations, including Canada, Japan, Republic of Korea, Mexico, People's Republic of China, Taiwan, U.S.A, and others. During the 1980s and 1990s, the catches have ranged between about 45,000 and 75,000 metric tons in the North Pacific.

There appear to be two subgroups of albacore in the North Pacific Ocean. The fish of the northern subgroup occur mostly north of 40°N when they are in the eastern Pacific Ocean. There is considerable exchange of fish of this subgroup between the troll fishery of the eastern Pacific Ocean and the baitboat and longline fisheries of the western Pacific Ocean. The fish of the southern subgroup occur mostly south of 40°N in the eastern Pacific, and relatively few of them are caught in the western Pacific. Fish that were tagged in offshore waters of the eastern Pacific and recaptured in the coastal fishery of the eastern Pacific exhibited different movements, depending on the latitude of release. Most of the recaptures of those released north of 35°N were made north of 40°N, and most of the recaptures of those released south of 35°N were made south of 40°N.

Childers and Miller (2000) presented the distribution of catches per day's fishing for albacore caught by U.S. troll vessels in 1999 in the North Pacific (Fig. 20). Childers and Miller also presented maps of albacore catch distributions in relation to SSTs in the North Pacific. Anonymous (2001a) presented distributions of catches per hook of albacore by Japanese longliners averaged over 1952-1976 (Fig. 21).

Time-series of recruitment, biomass, and average weights have not been prepared by the IATTC for albacore in the North Pacific Ocean. A time-series of length-frequency histograms of albacore caught by U.S. troll vessels in the North Pacific are presented in a series of reports by Childers and Miller (the latest is Childers and Miller 2000).

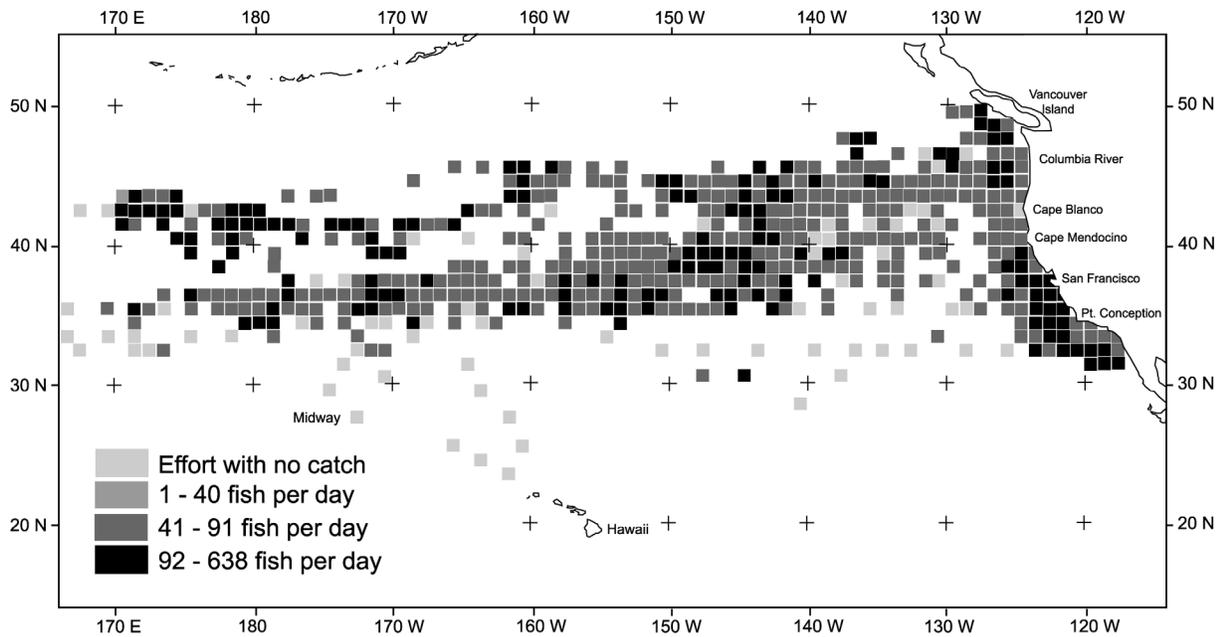


Fig. 20 Distribution of albacore CPUEs by U.S. troll vessels in the North Pacific Ocean during 1999 (from Childers and Miller 2000).

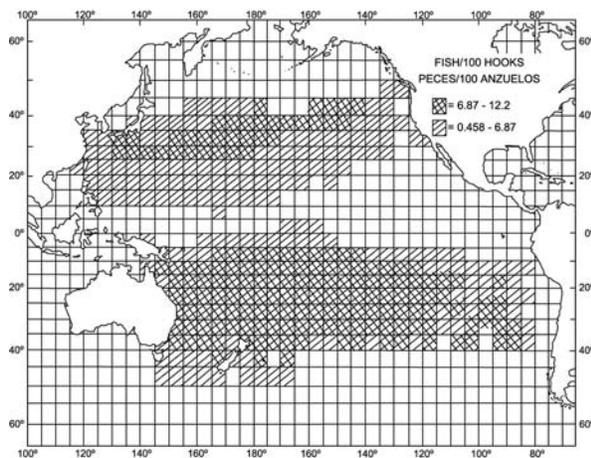


Fig. 21 Distribution of catches per hook of albacore by Japanese longliners averaged over the 1952-1976 period (from Anonymous 2001a).

Ecosystem model and climate forcing

The staff of the IATTC has been developing a modeling approach to evaluate the ecological implications of alternative fishing strategies in the pelagic tropical (EPO). Additional development and evaluation of the EPO ecosystem model was accomplished by a working group funded by the National Center for Ecological Analysis and

Synthesis (NCEAS) in Santa Barbara, California. One of the products of the working group was an evaluation of the implications of climate forcing on ecosystem dynamics of the tropical EPO. One of the ways that the physical environment affects ecosystem dynamics is by inducing variation in primary production at the base of the food web. The tropical EPO is strongly influenced by El Niño and La Niña events. Over a large portion of the tropical EPO, the chlorophyll concentrations are reduced during El Niño and increased during La Niña. To simulate ENSO-scale variations in producer biomass in the ecosystem model, the working group constructed an empirical model that relates SST anomalies to surface chlorophyll concentrations. They used time-series of SST anomalies to specify trajectories of producer biomass, and simulated the ecosystem effects of ENSO-scale pulses and cycles and a time-series of producer biomass predicted from a greenhouse-warming scenario for the 21st century. A manuscript describing the analysis has been submitted to *Fisheries Oceanography*, and is in review at the present time. The abstract of the manuscript (Olson *et al.* submitted) follows:

Evaluating the top-down effects of fishing on marine ecosystem dynamics requires an

understanding of the role of bottom-up physical processes. We used a recently-developed ecosystem model for the pelagic eastern tropical Pacific Ocean (ETP) to explore how El-Niño-Southern-Oscillation (ENSO)-scale variability might affect the animals at middle and upper trophic levels. We forced the model with ENSO-scale variations in primary-producer biomass that were estimated from an empirical relationship between observed sea-surface temperature (SST) anomalies and surface chlorophyll concentrations. We used time series of SST anomalies to specify trajectories of producer biomass, and simulated the ecosystem effects of 1) single, positive (La Niña-like) and negative (El Niño-like) pulses in producer biomass, 2) regular warm-cold cycles in producer biomass, and 3) a time series of producer biomass predicted from a greenhouse-warming scenario for the 21st century. Pulses in producer biomass in the model ecosystem affected components at middle trophic levels (forage fishes and cephalopods) more than the apex predators. Bottom-up forces acted as a wave propagating through the ecosystem at various time lags. Regular warm-cold cycles with low periodicity had the greatest impact, increasing the relative biomasses and biomass variability of organisms at middle trophic levels and decreasing those of organisms at higher trophic levels. The biomasses of all ecosystem components decreased during the long-term trend of the greenhouse-warming scenario, and only components with relatively high production/biomass ratios were sensitive to the high-frequency ENSO signal. Comparing simulations with and without fishing mortality allowed us to identify which ecosystem components are primarily top-down controlled by fishing and which are primarily bottom-up controlled by resource dynamics.

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Biological time-series for the central North Pacific

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The Northwestern Hawaiian Islands time-series

Since the early 1980s a number of the components of the Northwestern Hawaiian Islands (NWHI) ecosystem have been monitored annually. The following biological time-series are used as indicators of ecosystem dynamics: i) the reproductive success of red-footed booby and red-tailed tropic birds at French Frigate Shoals; ii) the composition of spiny and slipper lobster in the commercial landings at Maro Reef; and iii) the girth of weaned monk seal pups from 6 islands in the NWHI (Table 2).

The reproductive success of these two seabirds has been estimated by US Fish and Wildlife since 1980 as the ratio of number of chicks surviving to fledge to number of eggs laid (Fig. 22). Both seabirds feed on juvenile flying fish and squids around the NWHI, and variation in reproductive success is interpreted as a response to variation in prey availability.

Spiny (*Panulirus marginatus*) and slipper lobsters (*Scallarides squamossus*) are both caught in the commercial trap fishery for lobster. While the two species appear to have a similar ecology, the spiny lobster has a 12-month pelagic larval period while

the slipper lobster has a 3-month larval period. Fishery data has been collected with logbooks since 1983. Changes in their composition in the commercial catches reflect changes in relative abundance which may reflect changes in oceanographic process around the NWHI (Fig. 23).

Monk seal pup girth has been collected since the early 1980s at many of the islands in the NWHI. Pup girth measured within 2 weeks of weaning is thought to be an indicator of female foraging success during gestation which is transferred to the pup in the form of milk.

The Transition Zone time-series

The Transition Zone time-series are: i) the reproductive success of the black-footed albatross and the Laysan albatross; ii) the catch-per-unit of effort (CPUE) from the US troll fishery for albacore in the North Pacific; and iii) the winter position of the Transition Zone Chlorophyll Front (TZCF) (Table 2).

The reproductive success of the albatross have been estimated since 1980 by US Fish and Wildlife at French Frigate Shoals, as the ratio of chicks that fledge to number of eggs laid (Fig. 23).

Table 2 Biological indicators for the central North Pacific.

Northwestern Hawaiian Island

1. Reproductive success for red-footed booby and red-tailed tropicbird, 1980–present. Source: Hawaii and Pacific Island Refuge, USFWS (Fig. 22).
2. Research and commercial fishery lobster catches, 1983-present. Source: Honolulu Lab, NMFS.
3. Girth of weaned monk seal pups for 6 islands, 1983-present. Source: Honolulu Lab, NMFS.

Transition Zone

1. Reproductive success of black-footed and Laysan albatross, 1980-present. Source: Hawaii and Pacific Islands Refuge, USFWS (Fig. 22).
2. US North Pacific albacore troll fishery CPUE, 1960-present. Source: SWFSC, NMFS. (Fig. 23).
3. Winter position of the Transition Zone Chlorophyll Front, 1997-present. Source: Honolulu Lab, NMFS (Fig. 23).

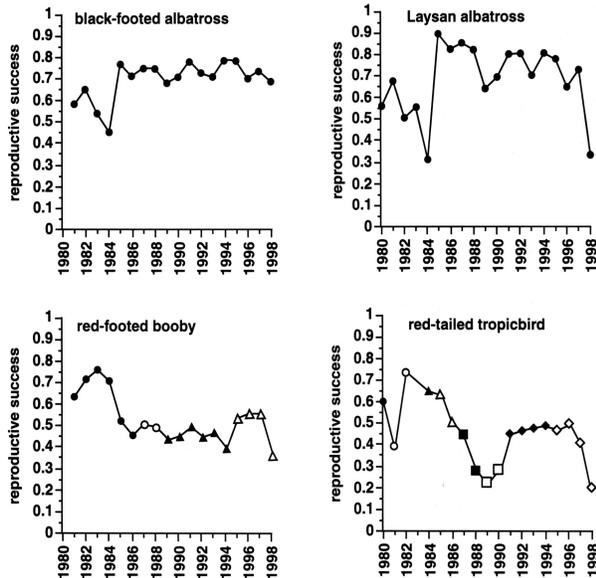


Fig. 22 Reproductive success of 4 species of seabirds nesting at French Frigate Shoal, Hawaiian Archipelago. Data from B. Flint, USFWS, Honolulu, HI.

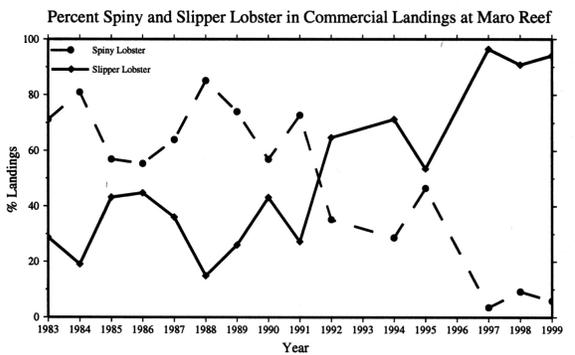
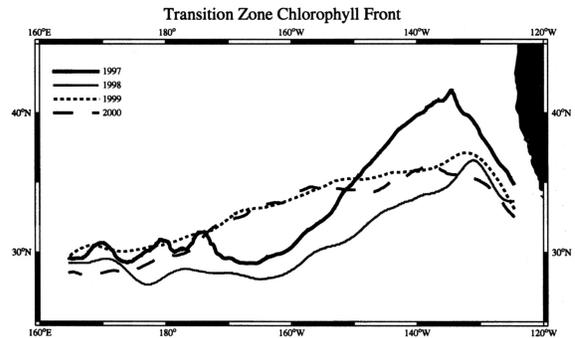
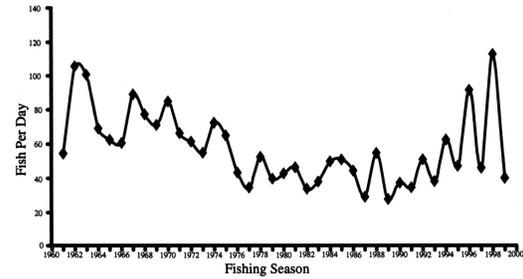


Fig. 23 Top: Catch-per-unit of effort in the US troll fishery for albacore; middle: winter position of the Transition Zone Chlorophyll Front; bottom: percentage of spiny and slipper lobster in commercial lobster fishery at Maro Reef, Hawaiian Archipelago. All data from Honolulu Laboratory, SWFSC, NMFS.

These birds forage north from Hawaii in the Transition Zone and perhaps beyond while rearing chicks. Variation in reproductive success is thought to reflect variation in prey availability.

Fishery data from the US troll fishery for albacore is available since 1961 (Fig. 23). The fishery begins in May in the Transition Zone near midway and follows albacore as they migrate eastward, reaching the coast of North America in the fall. An important part of the variation in troll CPUE is

thought to reflect the abundance and availability of albacore in the Transition Zone and hence is likely to be a function of population size and frontal strength.

The position and shape of the TZCF in January and February is measured from satellite ocean color data as the boundary between the high surface chlorophyll water of the Transition Zone, and the low surface chlorophyll water of the subtropical gyre. The boundary is measured as the 0.2mg/cubic ml chlorophyll-*a* contour line estimated with OCTS data in 1997 and Seawifs data beginning in 1998 (Fig. 23).

Interpretation of variation in time-series

The NWHI time-series show changes occurring during the period 1985-1991. Reproductive success of red-footed booby and red-tail tropicbird dropped from about 80% to 40% in the mid-1980s. There was a change in the composition of lobster in the fishery from about 70% spiny and 30% slipper from 1983-1991, followed by a sharp reversal of the proportion of spiny and slipper lobsters in the landings since 1992. Monk seal pup girth dropped at many of the islands in the late 1980s or early 1990s. These trends have previously been interpreted as part of a regime shift in the mid- to late 1980s (Polovina *et al.* 1994, Hare and Mantua 2000). However it is interesting that monk seal pup girth has shown an increase in 1998 and 1999, but no coherent change has been observed in lobster or sea bird data.

In the Transition Zone time-series, the albatross showed an increase in the mid-1980s and a drop in the late 1990s. The albacore CPUE shows a declining trend from the early 1960s to the early 1990s, followed by some evidence of an increase in the later 1990s. The TZCF shows 1999 and 2000 to be different from 1997 and 1998. The increase in albatross reproductive success in the mid-1980s is coherent with the changed in the NWHI time-series. It has been proposed that the decline in albacore CPUE since the mid-1970s was a response to the 1977 regime shift (Al Coan, Richard Parrish, pers. comm.). The changes in the late 1990s in the albatross, albacore, and TZCF may be responses to the strong El Niño and La Niña events or the beginning of a new regime. The change in the TZCF appears to reflect a warming in the central North Pacific and a cooling in the eastern North Pacific in 1999 and 2000, compared to 1997 and 1998 (Polovina and Seki 2000).

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Recent progress in salmon migration research in Japan

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In Japan, almost all chum salmon (*Oncorhynchus keta*) are produced by artificial enhancement programs. The number of adult chum salmon

returned to Japan from 1900 through 1970 averaged about 3 million individuals per year, ranging from 1 to 5 million individuals. Since the

late 1970s, adult returns have exponentially increased to more than 50 million individuals through the late 1980s, and reached 88 million individuals (57 million individuals in Hokkaido and 31 million individuals in Honshu) in 1996 (Fig. 24). This population size accounted for 70-80% of all the chum salmon caught in the North Pacific Ocean. The number of juveniles released increased from 800 million individuals in the early 1970s to 2 billion individuals in 1982, and has been limited to about 2 billion individuals since the early 1980s (Fig. 24). The rapid increase in chum salmon abundance, however, may have led to population density-dependent effects such as reduction in somatic growth and increase in age at maturity (Kaeriyama 1999). Therefore, it is extremely important to investigate the migration mechanisms of salmon in the North Pacific Ocean.

Since mass marking of hatchery salmon using otolith thermal marks is highly effective for stock identification of salmon, thermal mark programs have been carried out by the National Salmon Resources Center, Fisheries Agency of Japan, for the purpose to investigate ocean migration and survival of each regional salmon stocks. In April 1999, approximately 4 million chum salmon (1998 brood year) with three thermal mark patterns were released from the Chitose Hatchery in Hokkaido. This was the first trial of thermal otolith marking for anadromous salmon in Japan. We are planning to increase the number of thermal mark releases from hatcheries. A computer-programmed chiller system was developed to control water temperature, producing high quality thermal marks in the otoliths of chum salmon. To increase available thermal mark patterns, we employed

narrow rings, which were formed at 12 h intervals. In the spring of 2000, approximately 16 million chum and pink salmon (1999 brood year stocks) were released from hatcheries after thermally marked. We expect that more than a hundred million thermally marked chum salmon may be released in the spring of 2003. Figure 24 occupies about 5% of total hatchery releases in Japan (Urawa *et al.* 2000).

Recent rapid advances in biotelemetry technology on free-swimming fish make it possible not only to monitor underwater fish movement in greater detail, but also to analyze physiological aspects of fish behaviour. Three biotelemetrical instruments (ultrasonic transmitter, electromyographic radiotransmitter, and micro-datalogger) have been applied to investigate homing mechanisms in lacustrine sockeye salmon (*Oncorhynchus nerka*) and masu salmon (*O. masou*) in Lake Toya, Japan. These fishes offer good model systems for studying orientation ability in open water, energetics of migration, and environmental preferences of migrating fish. Moreover, hormone implantation experiments have revealed the direct influence of the brain-pituitary-gonadal axis on homing migration of lacustrine sockeye salmon in Lake Shikotsu, Japan. Although each technique has great advantages as well as minor disadvantages for clarifying physiological mechanisms of fish behaviour, combining different physiological biotelemetry has allowed us to understand the physiological mechanisms, and ultimately evolutionary adaptations, that facilitate successful homing migration (Ueda *et al.* 2000).

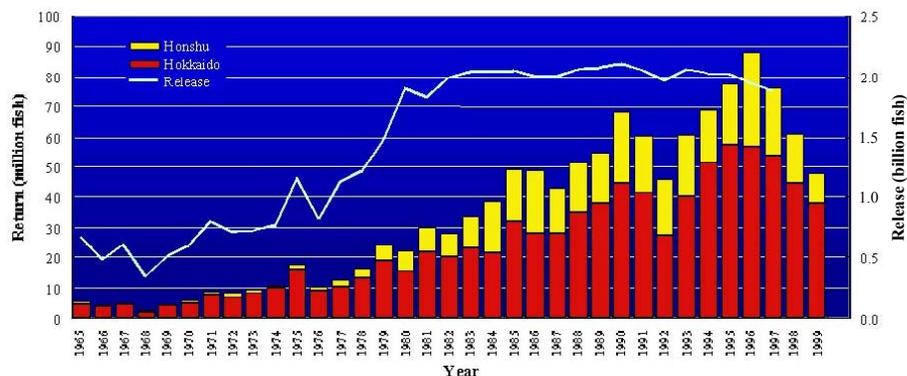


Fig. 24 Annual changes in number of adult returns and juvenile releases of chum in Japan during 1965-1999.

We are also trying to develop an automatic salmon-tracking robot boat that is composed of four interrelated equipment systems: 1) a robot boat, 2.5 m in length, 1.3 m in width, with a loading capacity of 120 kg, operated by two electric thrusters at 2 knots; 2) an ultrasonic tracking system detecting distance and direction of miniature pingers; 3) a signal processing and control system consisting of DGPS, acoustic signal, and gyroscope; and 4) a telecommunication system between a land base and the boat. The final goal of this project is to build a robot boat that can track an acoustic signal acquired from a salmon at a distance of 100 m. In the future, we plan to track salmon using the robot boat in the ocean.

We believe that salmon is one of the key species for monitoring climate-linked changes in biodiversity in the North Pacific Ocean, and will carry out collaborative research to investigate the homing migration and maturing mechanism by

means of biotelemetrical as well as fish physiological analyses.

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Seabird monitoring program at Teuri Island, Hokkaido, Japan

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A seabird monitoring program at Teuri Island (44°25'N, 141°19'E, Fig. 25) is carried out to analyze how annual variation of physical marine processes in the northern part of the Japan Sea affect seabird breeding performance through fish stock change. Target seabird species (Table 3) and time-series are:

- Black-tailed Gulls (BTG): 1980, 1984, 1985, 1987, 1992-2000;
- Slaty-backed Gulls (SBG): 1980, 1984, 1985, 1987, 1992-2000;
- Rhinoceros Auklet (RA): 1984, 1985, 1987, 1992-2000; and
- Japanese Cormorants (JC): 1992-2000.

A few parameters were missing in some years. Parameters including breeding number, timing of breeding (egg laying or hatching), breeding success (clutch size, egg size, no fledgling, chick growth), diet for chicks (prey composition in the

diet for chicks, meal size, fish size and number for bill load of RA) are measured according to the Teuri Island Seabird Monitoring Manual (Table 3).

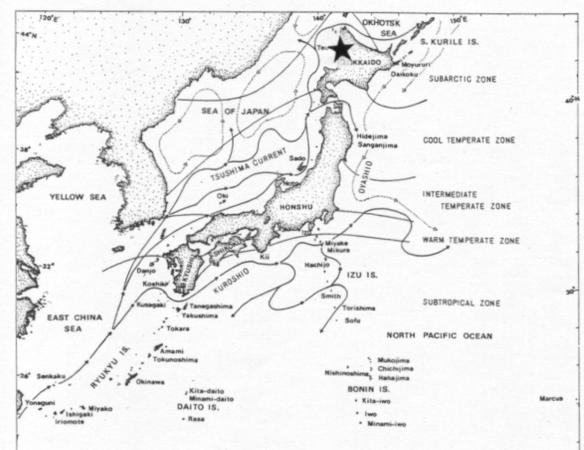


Fig. 25 Map showing the position of Teuri Island (marked by star).

Table 3 Monitoring seabird species and parameter at Teuri island.

	BTG	SBG	RA	JC
Number of nests	•	•		•
Time of egg laying	•	•		•
Time of hatching	•	•	•	•
Egg size	•	•		
Clutch size	•	•		•
Hatching success	•	•	•	•
No. fledgling per nest	•	•	•	•
Chick growth rate	•	•	•	•
Fledgling mass			•	
Fledging period			•	
Fledgling size			•	
Adult size and mass			•	
Prey composition	•	•	•	•
Prey fish size			•	

The breeding numbers of SBG and JC on the entire island are directly counted at the end of egg-laying season (late May). That of BTG is estimated with the number of birds on the entire island and number of nest/number of birds ratio obtained at 3 approximately 10 x 10 m plots. Egg laying, egg dimension, breeding success and chick growth of gull species are measured in a single permanent SBG plot (*ca.* 30 nests) and 2-3 BTG plots (*ca.* 30-60 nests). Each chick is color banded and weighed every 5 days. Those surviving more than 30 and 35 days are assumed to fledge for BTG and SBG, respectively. Nest contents of RA are checked and their chicks are weighed every 5 days in a permanent plot where more than 50 artificial nest boxes are used (at least 30 nests). Nest contents of JC in a semi-permanent plot (more than 30 nests) on a cliff are observed from a distance. JC chicks older than 45 days are assumed to fledge. Chicks of at least 10 nests of JC are weighed every 5 days between late May and late June. Site of chick weighing plots is changed every year. Chick growth rate is calculated as the slope of linear regression through

the linear growth stage (5-25 days for SBG, 5-20 days for BTG, 0-20 days for RA, and 0.2-2.0 kg for JC). Fledgling mass and age of RA in the plot and final mass of chicks of two gull species are reported. Body size and mass of more than 30 fledglings of RA captured arbitrarily are reported also.

More than 30 regurgitations from chicks and chick rearing adults are collected from BTG, SBG and JC each year. Wet mass proportion and number of samples contained in each prey categories are measured. About 10 food loads of RA are collected every week from birds landing at night with food. Fish are identified and length and mass are measured. At the same time, body size and mass of these birds are measured. Mass prey composition in the diet for Black-tailed Gulls (BTG) and Rhinoceros Auklets (RA) chicks at Teuri Island is shown in Figure 26.

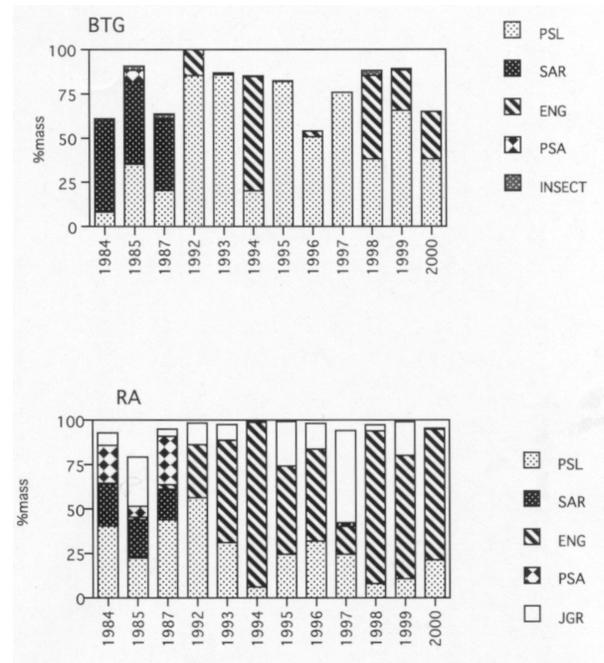


Fig. 26 Between-year difference in mass prey composition in the diet for chicks from Black-tailed Gulls (BTG) and Rhinoceros Auklets (RA) at Teuri Island. Abbreviation are PSL, sandlance; SAR, sardines; ENG, anchovy; PSA, saury; JGR, juvenile Japan Sea greenling.