TRINATIONAL SARDINE FORUM
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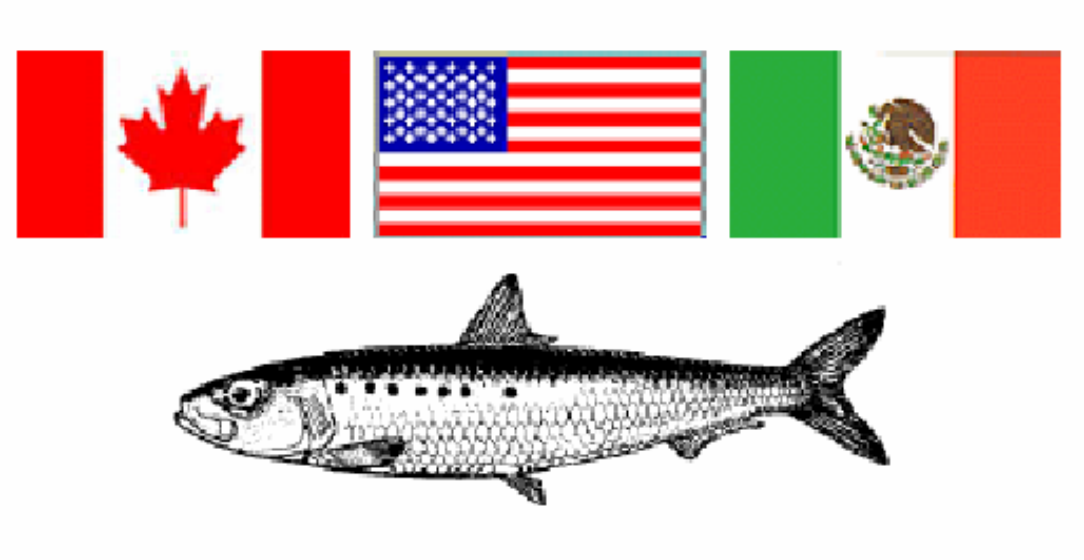
ABSTRACTS



Sardine and its role in the ecosystem

Harbour Towers Hotel
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November 18, 2010 - Workshop

CONTENTS

TUESDAY NOVEMBER 16TH

WEDNESDAY NOVEMBER 17TH

TRINATIONAL SARDINE FORUM
DAY 1
NOVEMBER 16, 2010

Bahia Magdelena sardine fishery 2009-2010

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The sardine fishery in Bahia Magdalena has been shown a declining trend during last five years. Total landings in 2006 were 58,237 mt whereas in 2010 (January to August) landings decreased to 21,061 mt. During 2009, 530 fishing trips were carried out and 45,106 mt of small pelagic fishes were caught. In 2010, catch of the Pacific sardine (Sardinops sagax) was 36,338 mt, representing 92.8% of total catch. Other species landed included Opisthonema sp (3.7%), Cetengraulis mysticetus (2.9%), Etrumeus teres (0.2%) and Scomber japonicus (0.3%). Pacific sardine was caught throughout 2009 (except in December), although 81% of landings were from May to August and 73.6% of fishing trips were carried out at this time. Size of Pacific sardine ranged between 121-200 mm SL. Only 33.2% of sardines caught were above the minimum legal size (150 mm SL). Five age groups (0 to 4) were found, although age group 1 was the most abundant (78.4%). During January to August 2010, 21,061 mt of small pelagic fishes has been caught in 316 fishing trips. Pacific sardine catch was 8,172 mt and represented only 38.8% of total landings. Pacific sardine practically disappeared of Bahia Magdalena during ten months (September 2009-June 2010).Others species caught in these months of 2010 were Opisthonema spp with 4,960 mt (23.5%), 6,682 mt (31.7%) of Etrumeus teres, 387 mt (1.8%) of Cetengraulis mysticetus, and 860 mt of a mix of species (4.1%). Biological samples of Pacific sardine taken during 2010 haven't still been analyzed.

Assessment of the Pacific sardine resource in 2010 for U.S. management in 2010

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The Pacific sardine resource is assessed each year in support of the Pacific Fishery Management Council (PFMC) process that, in part, establishes an annual harvest guideline ('HG') for the U.S. fishery. The following assessment update for 2011 management is based on data sources and methodologies described in detail by Hill et al. 2009 and Jagielo et al. (2009), and reviewed by a STAR Panel during September 2009 (STAR 2009). In this update, we append fishery-dependent and survey series with more recently available information, without changes to base model structure or parameterization. A preliminary draft assessment was reviewed by the SSC's CPS-Subcommittee October 5-7, 2010, in La Jolla, California. Modifications to input data were incorporated during the course of that review, resulting in changes to population estimates and management-related quantities. The present report has been updated to reflect those changes.

Data and assessment

This assessment update was conducted using 'Stock Synthesis' version 3.03a and utilizes fishery and survey data collected from mid-1981 through mid-2010. The model uses a July-June 'model year', with two semester-based seasons per year (S1=Jul-Dec and S2=Jan-Jun). Fishery data include catch and biological samples for the fisheries off Ensenada, Southern California, Central California, and the Pacific Northwest. Two indices of relative abundance are included in the base model: Daily Egg Production Method and Total Egg Production estimates of spawning stock biomass (1986-2010), both based on annual surveys conducted off California. Finally, the 'tuned' update model '10w' was run with the addition of aerial (northern region) survey estimates of absolute abundance from 2009 and 2010 (q=1) to derive population quantities for 2011 management.

The update model '10w' had the following specifications, per Hill et al (2009):

- Model Year based on the July 1 birth date assumption (July 1-June 30 time span);
- Assessment years 1981-2010; Two semesters per year (S1=Jul-Dec; S2=Jan-Jun);
- Four fisheries (ENS, SCA, CCA, PNW), with annual selectivity patterns for ENS and PNW and seasonal selectivity patterns for SCA and CCA (S1 & S2).
- Use of length-frequency and conditional age-at-length data for all fisheries;
- Length-based, double-normal selectivity with time-blocking:
    - ENS, SCA_S1, & SCA_S2: 1981-91, 1992-98, 1999-10;
    - CCA_S1 & CCA_S2: 1981-92, 1993-98, 1999-10;
    - PNW: 1981-03, 2004-10;
- M = 0.4yr^{-1} for all ages and years;
- Time-varying growth in two periods: 1981-90 and 1991-10;
- Ricker stock-recruitment relationship; σ_R = 0.815; Steepness estimated;
- Initial recruitment (R_1) estimated; recruitment devs estimated from 1975 to 2008;
- Hybrid-F fishing mortality option;
- DEPM and TEP measures of spawning biomass (1986, 1987, 1993, 2003, 2004, and 2006-2009 for DEPM, and 1987, 1995-2002 and 2005 for TEP) and aerial survey estimates of abundance from 2009 and 2010.
- Length-frequency data for the 2009 and 2010 aerial surveys, taken from point-set samples, fit with a single selectivity function (double-normal, dome-shaped).

Stock biomass and recruitment

Stock biomass, used for determining the HG, is defined as the sum of the biomass for sardines ages 1 and older. Biomass increased rapidly through the 1980s and 1990s, peaking at 1.57 mmt in 2000. Biomass has subsequently trended downward to the present (July 1, 2010) level of 537,173 mt.

Recruitment was modeled using the Ricker stock-recruitment relationship. The estimate of steepness was high (h=2.253). Virgin recruitment (R0) was estimated at 4.62 billion age-0 fish for the base model. Recruitment increased rapidly through the mid-1990s, peaking at 17.156 billion fish in 1997, 19.743 billion in 1998, and 18.578 billion in 2003. Recruitments have been notably lower from 2006 to 2009.

http://www.pcouncil.org/wp-content/uploads/I2b_ATT2_ASSMT_UPDATE_NOV2010BB.pdf

Regional estimates of biomass of Pacific sardine in 2010 and recent years

Working group 1: Yanira Green-Ruiz, Tim Baumgartner, Martin E. Hernandez-Rivas, Sandy McFarlane, Jake Schweigert, Vanessa Hodes, Robert Emmett, John Ferguson, Rayn Kapp, Tom Jagielo, Ryan Howe, Dave Demer, Juan Zwolinski, Beverly Macewicz, David Griffith, and Nancy C.H. Lo

This report updates time series of estimates of spawning biomass and biomass based on data collected during surveys on Pacific sardine conducted up to 2010 off the west coast of the American continent. These surveys are 1. Investigaciones Mexicanas de la Corriente de California (IMECOCAL) survey off Mexico, 2. April Daily egg production-California Current Ecosystem (CCE) coast wide survey from California to Washington boarder by the Southwest Fisheries Science Center, 3. The Northwest Fisheries Science Center (NWFSC) summer night time trawl survey near Columbia River and the Bonneville Power Administration (BPA) Columbia River plume study with day time trawls. 4. The NW aerial survey by the West Coast sardine industry and 5. Canadian West Coast Vancouver Island (WCVI) trawl survey. All NW surveys were conducted in the summer time except the CCE coast wide surveys which were conducted in both spring and summer when funding is available. Note, the spawning biomass from the IMECOCAL surveys are available only for years of 1997-2003. The NWFSC did not conduct their summer standard surveys in 2010 due to no fishing vessel bid on the contract for this field work. Yet, size/age data for May/June 2010 from plume and Columbia River estuary were collected.

Estimate of the spawning biomass of Pacific sardine off California in 2010 was 108,000mt compared to 180,000mt in 2009. Estimate of biomass off British Column was 67,000mt compared to 198,000mt in 2009. Estimate of biomass from the NW aerial survey was 201,000mt compared to 1.2 million mt in 2009. The preliminary estimate of biomass from the acoustic measurement taken during the 2010 April CCE survey was 350,000 mt compared to 0.8 million mt in April 2008. All four time series gave a strong signal that the population of Pacific sardine off US and Canada is declining. To understand the dynamic of the Pacific sardine off the west coast of the American continent, we need to asses the entire population of Pacific sardine and its relationship with the environment from BC to BC periodically.

Pacific sardine abundance and associated oceanographic conditions off northern Oregon and southern Washington in 2010

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Two fishery oceanographic surveys, which collect juvenile and adult sardines and measure environmental conditions off Washington/Oregon, were conducted in 2010. However, the Predator Survey, which has been conducted data annually since 1998, had severely reduced sampling because of the inability to contract a fishing vessel to conduct this research. As such we were unable to estimate biomass off the Columbia River in 2010. Some limited age analysis revealed that sardine did spawn successfully in 2009, probably because ocean temperatures were much warmer than 2008. Preliminary data indicate that sardine also successfully spawned and recruited off the Pacific Northwest in 2010. However how this recent recruitment in the Northwest will influence future adult sardine abundance is presently uncertain.

Preliminary results of the 2010 West coast Vancouver Island sardine trawl survey and the use of aerial survey data

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Summer surveys directed at collecting information on sardines off the WCVI started in 1997. Fishing is conducted in surface waters ($\leq$ 30 m) using a mid water trawl towed at average speeds approximating 4-5 knots. Since 2006, sampling has been conducted at night. In 2010, the locations of stations were determined by randomly selecting sites along a 10x10km grid representing approximately equal sampling intensity in 4 zonal divisions of the region. The method of selecting stations in 2010 differed from past years in order to try to minimize potential bias associated with estimating biomass. In 2010, 70 sets representing an area of approximately of 17,000 km^2 were sampled. Forty of the 70 sets collected sardines, with many of the zero sardine hauls observed in the northern portion of the survey region. A preliminary estimate of ~ 70,000 metric tons was derived for the region using the method of expanding each stratum's average catch density (t/km^3) over an estimate of its spatial size (km^3) and then summing across strata. Juvenile sardines (age 1) dominated the catch of a single tow made offshore of Kyuquot Sound and were found in low numbers in several other sets. The range in size of these smaller fish is 123- 165 mm. All other sardine catches consisted predominately of adults (ages 3-10) with a size range of 176 to 288 mm (mean ~ 23 cm).

In 2009 and 2010, aerial survey trials were conducted to collect images representing sardine habitat with possible showings of schools. Results from these test trials will be aimed at evaluating technical parameters for possible future applications.

Error in Pacific sardine assessment arising from spatial structure assumptions

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The results (and credibility) of stock assessments can be impacted by assumptions regarding spatial structure and movement. For the northern sub-population of Pacific sardine (*Sardinops sagax caerulea*), seasonal length-dependent migration has been described in the literature, as well as the possible presence of two stocks, rather than one. However, the current assessment, conducted using the Stock Synthesis 3 (SS3) framework, assumes a spatially-aggregated stock with constant growth across the entire coast and fleets with different selection patterns in the four areas included in the assessment (Ensenada, southern CA, northern CA and Pacific Northwest). We propose a simulation-based approach using an operating model including several hypothetical scenarios of spatial structure and seasonal movement, on which the performance of SS3 can be evaluated to determine (1) how much error can arise because assessments of sardine are conducted using a spatially-aggregated stock assessment method when this assumption is violated, and (2) whether moving to a spatially-structured stock assessment could reduce this error. The focus of this presentation will be on working hypotheses and an introduction of the project.

The 2010 California Current Ecosystem survey, summary and comparison to Pacific sardine caught in 2006 and 2008 spring coastwide surveys

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Trawling during the April 2010 CCE survey covered a large area off the west coast of the U.S. from Cape Flattery, WA to San Diego, CA. Previous trawling was conducted off the whole west coast in the spring during 2006 and 2008 (Lo et al. 2007a, 2008). None of the 8 daytime trawls captured sardines while 18 of the 90 nighttime trawls contained sardines in 2010. We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in three subareas off the coast: Washington and Oregon (9.5-11.4^{o}C), northern CA (9.6-13.2^{o}C), and the standard DEPM area (12.1-15.9^{o}C). The 2010 temperature ranges were warmer than those during 2008, and while similar to the warmer temperatures in 2006 off Washington and Oregon, no eggs or adults were found in 2010. In all three surveys, sardines sampled were larger in the northern CA area, although much fewer in number, than in the standard DEPM area. In the standard DEPM area, sardine adults and eggs were always collected, and although the size of female sardines caught has increased from 67g in 2006 to 105g in 2008 and to 127g in 2010, the size of Region 1 (high sardine egg density) and P_0 (daily egg production) has decreased during this period of time. In addition the mean size of sardines (male and females) was slightly larger in 2010 (219 mm) than in 2008 (212 mm) and 2009 (211 mm), but there were very few sardines (0.9%) of sizes 175 mm to 194 mm SL compared to 2009 (8.6%) and 2008 (12.4%). These trends in the DEPM area coupled with the decrease in the spawning biomass since 2006 may indicate decreasing recruitment of recent year classes.

An acoustic-trawl method for surveying epipelagic fishes, and biomass estimates for the dominant species in the California Current Ecosystem during 2006, 2008, and 2010

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The abundances of epipelagic fish species in the California Current Ecosystem (CCE), from San Diego to Southern Vancouver Island, were estimated from combined acoustic and trawl sampling in the spring of 2006 and 2010, and summer of 2008. Pacific sardine, jack mackerel, and Pacific mackerel were the dominant coastal pelagic species (CPS). Anchovy and herring were sampled only sporadically. The estimates of Pacific sardine biomass compare well to those of the annual assessments and confirm that the stock has been declining since 2006. Concurrently, the biomass of jack mackerel has been increasing. The estimated biomass of Pacific mackerel is relatively low and variable. Future surveys of CPS in the CCE should benefit from: adaptive sampling based on modeled CPS habitat; increased acoustic and trawl sampling, particularly of species with patchy distributions and low biomasses; and directed-trawl sampling for improved species identification and target strength estimation.

Predicting habitat for optimizing acoustic and egg sampling of Pacific sardine

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Prior to the collapse of the Pacific sardine fishery in the 1950s, the stock exhibited seasonal migrations which spanned the entire west coast of North America. The sardine routinely spawned off the Southern California Coast in the spring, and migrated northwards, as far as Canada, during the summer. During the subsequent decades of low abundance, however, the sardine appeared to remain in Southern California waters. When the stock increased in the 1990s, the seasonal migration pattern and the summer fishery off Oregon, Washington, and British Columbia were restored. The stock is assessed and managed using a catch-at-age model with fisheries independent abundance estimates from the Daily Egg Production Method and aerial surveys. In response to the Pacific Fishery Management Council's call for additional fishery-independent estimates of sardine biomass, the Southwest Fisheries Science Center began conducting acoustic-trawl surveys of sardine in the spring of 2006. To reduce the sampling error, the survey effort must be optimally applied to only potential sardine habitat. Presented here is a generalized-additive model of potential sardine habitat which is based solely on satellite-sensed oceanographic conditions. Described are the methods used for avoiding spatial auto-correlation in the data and selecting the most important environmental variables. The best model accurately predicts both the boundaries of the spawning stock during the spring-spawning season, and the spawning and non-spawning sardine during their summer migration. These predictions accurately match the annually-observed summer arrival of sardine off the mouth of the Columbia River, approximately 1000 km north of the main spawning area. Furthermore, the model predicts the historically-observed seasonal cycle of potential sardine habitat, and the summertime fishery off Oregon, Washington, Vancouver Island throughout the last decade. Quasi-real-time predictions of potential sardine habitat allow optimizations of survey time, place, and sampling effort.

Too hot or too cold? How Pacific sardine respond to temperature fluctuations

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Coastal pelagic fish species such as Pacific sardine (*Sardinops sagax*) undergo large fluctuations in abundance that end up affecting the marine ecosystems and the economies of countries worldwide. Climatic fluctuation has been suggested as a strong driver for these population booms and busts, but little work has been done to understand the effect of temperature on sardine physiology. In this study, our objective was to understand the optimal physiological temperature range of Pacific sardine collected April-May off the southern California coast. These sardine likely represent the hypothesized "cold" stock of sardine. We subjected the sardine to slowly changing temperatures ranging from 9°C to 25°C. We sampled sardine at 9°, 11°, 13°, 15°, 17°, 19°, 21°, 23° and 25°C for blood plasma, heart, liver, and white muscle tissue. These tissues will be used to measure enzyme kinetics and gene expression of heat shock proteins and immune genes to identify an optimal temperature range for sardine. We will present preliminary results of specific activity and Michaelis-Menton constants of LDH in white muscle tissue, and gene expression levels of Hsp70 and Hsp90 in the liver. These preliminary results will provide insight as to how sardine respond to fluctuating temperatures and into their optimal temperature range.

TRINATIONAL SARDINE FORUM
DAY 2
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Re-assessment of the stock-recruit and temperature-recruit relationships for Pacific sardine (*Sardinops sagax*)

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The harvest guideline for Pacific sardine (*Sardinops sagax*) incorporates an environmental parameter based on averaged surface temperatures at the Scripps Institution of Oceanography pier (SIO pier) in La Jolla, California, USA that would be invoked after a series of cool years to reduce commercial catches using a precautionary decision rule. We revisit the stock-recruit and temperature-recruit relationships underpinning the currently used environmental parameter for sardine assessment and found that the temperature-recruit relationship no longer holds for the SIO pier when time series are updated with data from more recent years. The significance of the correlation between temperature and recruitment was also artificially increased by autocorrelation in the time series. In contrast, the stock-recruit relationship was still valid when recent data were added. SIO pier surface temperatures are warmer than 10m-depth Southern California Bight (SCB) temperatures where the sardine spawn, and the difference has increased since the late 1970s. Sardine recruitment was also not related to offshore temperatures in the SCB. We demonstrate that the environmental proxy derived from SIO pier temperature, which has never affected the harvest guideline since its implementation, no longer predicts recruitment of Pacific sardine, and should be removed from sardine management.

Trophically-transmitted parasites as biological tags suggest two migration patterns of Pacific sardines (*Sardinops sagax*) throughout the California Current System

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We assessed the migration patterns of Pacific sardine within the California Current System (CCS) using trophically-transmitted parasites. Approximately 2500 sardines were collected from 2005 through 2008 between 50^{o} to 31^{o} North latitude, and 120^{o} to 125^{o} West longitude. We have examined parasite communities as well as population genetics of four parasite species. Among the twelve parasite species recovered from approximately 1500 sardines, two parasite species show strong potential as biological tags. The trematode *Lecithaster gibossus* is prevalent in the parasite community of sardines caught in British Columbia waters, whereas the trematode *Myosaccium ecaude* is prevalent in sardines caught off California. Although Pacific sardines caught off Oregon and Washington can have either trematode, we found little overlap between the ranges of the two species and few individual sardines harbored both species. These results suggest limited migration throughout the expanse of the CCS. A comparison of the macroparasite communities of non-migratory northern anchovy (*Engraulis mordax*) collected off of Washington in 2007 and off southern California in 2008 supported *L. gibossus* as a biological tag from northern regions of the CCS. Results of population genetic studies of larval Anisakid nematodes and the trematode *M. ecaude* showed panmictic distributions with no regional differences. In summary, the examination of the parasite communities of Pacific sardine caught between 2005 and 2008 suggests two different migration patterns that overlap off of Oregon and Washington, but suggest little migration between southern California and British Columbia during those years.

Fishery and reproduction of the Monterey sardine *Sardinops caeruleus* in the West Coast of Baja California

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In Mexico, small pelagic fisheries (sardines, anchovy, mackerel), are the most important in landings (by weight). Fishery management requires knowledge about the reproductive biology of these species'. Random samples of sardines were taken from the landings of the commercial fleet in the west coast of Baja California for biometric data. Samples of gonad tissue were processed in the laboratory; and histological criteria were used to estimate the reproductive condition. A size frequency distribution was obtained and specimens ranged from 108 to 240 mm SL, with an average of 188 mm SL. The reproductive peak was identified in March, and smaller peaks occurred during June and December. The length at maturity was also estimated. We show and discuss features of the relationship between length at maturity, spawning seasonal, and temperature.

Abundance and growth rate during early life stages of Pacific sardine *Sardinops sagax* in the California Current ecosystems

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Population growth of Pacific sardine *Sardinops sagax* results from successful recruitment, which depends on high growth and survival during the early life stages. We examined interannual variation in growth rate during larval and early juvenile stages of *S. sagax* by comparing daily growth increments in otoliths to population growth in the 1980s to 1990s off California. Archival otoliths of juvenile *S. sagax* (100 – 160 mm in standard length) archived by the California Department of Fish and Game were used for the growth analysis. Otolith increment width (IW), which varies with daily somatic growth rate, was measured for up to 150 days after hatching and averaged during 30 d intervals from hatching. Mean IW during late larval stage (61-90 d) increased with the increase in recruit abundance in the 1990s. In contrast, mean IW during early juvenile stage (121-150 d) decreased in the 1990s and was negatively correlated with spawning stock biomass. This indicates that population growth of *S. sagax* in the early 1990s resulted from higher survival rates depending on faster growth rates during the late larval stage. Decrease in growth rate during the early juvenile stage in the late 1990s may be caused by density dependent effects, such as food limitation after onset of schooling and filter feeding.

The effect of the environment on California's commercial fisheries

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Long-term, naturally occurring cycles can cause significant shifts in marine ecosystems referred to as "regime shifts". While the new regime can be as diverse and ecologically acceptable as that which it replaced, individual species may completely disappear or be greatly depressed when a regime shift occurs. In this work we examine an 80 year time series of California commercial fishery landings during which time the California current has been observed to shift from a warm to a cold then back to a warm regime. This period also captures the heyday of the U.S. Pacific sardine fishery in the 1930s, its collapse and its subsequent reemergence in the 1990s. We observe major changes in the species composition of commercial landings over this period and relate these changes to changes in the environment as expressed through changes in the forage base. Our initial findings suggest that while aggregate biomass may not be greatly affected by a regime shift, there can be significant changes in the operations of fisheries and in the economic value they generate.

The value of fisheries along the California Current: a preamble to economic analyses

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The fluctuations in the sardine stock associated with the California Current (CC) marine ecosystem can have important implications along its distribution area, both for the ecosystem and for fisheries, underlining the need to develop ecological and bioeconomic models that are dynamic and spatially explicit. In order to define their criteria and potential objectives, the system must be characterized in ecological and economic terms. We begin by identifying the main fisheries target groups that occur along the CC, along with their ecological linkages. We then present the economic value of the CC fish stocks to the countries that share this ecosystem. The goal of this contribution is to lay the foundation for ecosystem-economic models of the CC that will allow us to explore the outcomes of alternative ecological and management scenarios.

Sardine, a fisherman's perspective

John Lenic[1]

1. Canadian Pacific Sardine Association

The FAO technical guidelines for responsible fisheries states in section 4: Precautionary approach to fishery research, guideline 57 "*Recognizing that resource users have substantial knowledge of fisheries, a precautionary approach makes use of their experience in developing an understanding of the fishery and* its impacts." Pacific Sardines are unlike other pelagic species and as such may require a rethinking of traditional stock assessment methods. An understanding of the inherent characteristics of sardines may influence the protocol of assessment or even the fundamental understanding of the stock itself. Fishers have an intrinsic understanding of schooling behavior, seasonal variation in stock dynamics and the idiosyncrasies of the animal itself.

An End-to-End trophic model for the Northern California Current: inter-annual variability in food web structure and impacts upon Pacific sardine

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Hydrographic, plankton, seabird, and fish surveys conducted from 2003 - 2007 provide time-series data on pelagic community composition on the Oregon and Washington shelf. We synthesize this dataset into a series of independent, mass-balanced food web models from which we infer inter-annual changes in both direct and indirect top-down and bottom-up pressures acting upon Pacific sardine (*Sardinops sagax*). We next develop end-to-end models for the NCC as bottom-up transformations of the top-down balanced models built within the Ecopath platform. An end-to-end model maps the flow of production through the entire food web from the input of nutrients to the production of top predators and fisheries and back to recycled nutrients. The top-down Ecopath solution for the predation matrix (the consumption of each producer group by each higher trophic level consumer group) can be transformed mathematically to a bottom-up matrix as detailed in Steele, 2009 (J. Mar. Sys. 76: 186-194). In this study, we use end-to-end models to investigate the propagation of parameter uncertainty upwards through the web, analyze system sensitivity to variability in the strength of individual trophic linkages, and test the effects of alternate trophic linkage arrangements (scenario testing) upon Pacific sardine production.

Potential ecological performance indicators for the South Australian Sardine Fishery

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The South Australian Sardine (*Sardinops sagax*) Fishery (SASF) was established in 1991 and is Australia's largest fishery by weight. Like all South Australian fisheries, the SASF is managed according to the principles of Ecologically Sustainable Development (ESD), which means that fisheries management decisions must balance ecological, economic, social and inter-generational equity considerations. Entry is limited to 14 licence holders. There are input controls, including limitations on net size. A Total Allowable Catch (TAC) is set annually and there are 14 equal Individual Transferable Quotas (ITQs). Industry takes a proactive role in management and other stakeholders are also involved. The costs of research, management and compliance are funded by industry through licence fees. The Management Plan identifies the biological, ecological, economic and social objectives of the SASF and outlines the framework of performance indicators, reference points and decision rules that has been established. Fishery-independent stock assessments are undertaken annually or biannually using the Daily Egg Production Method (DEPM). Stock assessments that utilise an age-structured population model are undertaken in years when fishery-independent surveys are not conducted. The baseline TAC of 30,000 t is maintained while estimates of spawning biomass remain between the limit reference points of 150,000 and 300,000 t (exploitation rates of 10-20%). Interactions with protected species have been assessed with through an independent observer program. An industry Code of Practice has been established to mitigate interactions with the short-beaked common dolphin (*Delphinus delphis*).

In 2004, an ecological study was initiated to: 1) assess the importance of sardine in the diets of key predators in the eastern Great Australian Bight (eGAB); 2) develop an ecosystem model for the region and 3) evaluate the potential for establishing ecological performance indicators for South Australian Sardine Fishery. The foraging patterns and reproductive biology of numerous pelagic fishes, squids, marine mammals and seabirds were examined. Catch data for the SASF was included in dietary analyses to facilitate comparison of the fishery with the consumption patterns of the 37 predator groups that were identified. The most important prey type in the eGAB was the Australian krill, followed by sardine, anchovy, Gould's squid and other crustaceans, which collectively accounted for 52.4% ± 21.4% of consumption. Eight guilds of predators were identified. The SASF was included in a guild with ten other predator groups that included several pelagic fishes (skipjack tuna, southern bluefin tuna, Australian salmon, snook, barracouta), the common dolphin and several seabirds (crested terns, Australian gannets, little penguins). This guild was defined mainly by the importance of sardine and anchovy in the diet and included the species that may be most likely to be affected by competition with the SASF.

Ecopath with Ecosim software was used to develop a trophic mass-balance model of the eGAB ecosystem. Four key parameters were estimated for each of 40 functional groups: diet, biomass, production per unit of biomass (P/B) and consumption per unit of biomass (Q/B). Data on landings, discards and effort for eleven fisheries (fleets) were included in the model. A time series of primary productivity data was also included. Model outputs suggested that significant changes occurred in the eGAB ecosystem between 1991 and 2008. These included a ~5 fold increase in total catch, which was entirely attributable to growth in the SASF, and a corresponding reduction in the mean trophic level of the catch (mTLc). The biomass of several fishes, seals, dolphins and seabirds also increased through combined effects of reduced effort in other fisheries, and an increasing trend in primary productivity. The increase in Kemptons Q biodiversity over the study period shows that the rise in mLTc reflects the growth of the SASF rather than a reduction in high trophic level biomass relative to lower levels. The high Fishing in Balance (FIB) index suggested that current catch levels are not impairing ecosystem function.

Modelling indicated that many groups are sensitive to changes in sardine biomass, but sensitivity analyses based on mixed trophic impacts detected negligible fishery impacts on these groups, despite the fishery's rapid growth since 1991. Of the land-breeding marine predators, which may be the most tractable as EPIs, crested terns demonstrated the greatest sensitivity to reductions in sardine biomass both in direction (negative) and magnitude, followed by Australasian gannets and little penguins. Demographic studies have indicated that the offspring of the crested tern were smaller and had lower survival rates in years following two major sardine mass mortality events. This species appears to have the greatest potential as an ecological performance indicator for the SASF. The trophodynamic model developed in this study will be a critical tool for distinguishing the potential impacts of the SASF from those related to changes in other fisheries or in environmental conditions.