Completion Report

Punt, Andre

Period: 2/1/2012 - 1/31/2013
Project: R/LME-2 - *Accounting for spatial structure in stock assessments: the case of Pacific sardine*

:: STUDENTS SUPPORTED

Ferro, Felipe Hurtado, fhurtado@u.washington.edu, University of Washington, School of Aquatic and Fishery Sciences, status:cont, *no field of study*, advisor:A.E. Punt, degree type:PhD, degree date:2015-06-01, degree completed this period:No
Student Project Title:
Management of small pelagic fishes

Involvement with Sea Grant This Period:
Funded Grad Research Assistant

Post-Graduation Plans: *none*

:: CONFERENCES / PRESENTATIONS

Hurtado-Ferro F. (Presenter), Punt A.E., Hill K.T.
The impact of spatial structure on the Pacific sardine assessment.
Oral presentation
The XIIIth Trinational Sardine Forum Annual Meeting
Seattle, WA,
, public/profession presentation, 40 attendees, 2012-11-28

:: ADDITIONAL METRICS

K-12 Students Reached:0

Curricula Developed:0

Volunteer Hours:0

Cumulative Clean Marina Program - certifications:0

Acres of degraded ecosystems restored as a result of Sea Grant activities:0

Resource Managers who use Ecosystem-Based Approaches to Management:0

HACCP - Number of people with new certifications:0

:: PATENTS AND ECONOMIC BENEFITS

No Benefits Reported This Period

:: TOOLS, TECH, AND INFORMATION SERVICES

Description		Developed	Used	Names of Managers	Number of Managers
Operating model to assess estimation methods, management strategies for fish populations along the coast. R/LME-2	**Actual** (2/1/2012 - 1/31/2013) :	1	1		0
	Anticipated (2/1/2013 - 1/31/2014) :	0	0		

:: HAZARD RESILIENCE IN COASTAL COMMUNITIES

Name of coastal community	County		Number of resiliency trainings / technical assistance services *provided*	Was community hazard resiliency improved (e.g., via changes in zoning ordinances) ?
None		**Actual** (2/1/2012 - 1/31/2013) :	0	0
		Anticipated (2/1/2013 - 1/31/2014) :	0	0

:: ADDITIONAL MEASURES

Safe and sustainable seafood

Number of stakeholders modifying practices
Actual (2/1/2012 - 1/31/2013) : 0
Anticipated (2/1/2013 - 1/31/2014) : 0
0

Number of fishers using new techniques
Actual (2/1/2012 - 1/31/2013) : 0
Anticipated (2/1/2013 - 1/31/2014) : 0
0

Sustainable Coastal Development
Actual (2/1/2012 - 1/31/2013) : 0
Anticipated (2/1/2013 - 1/31/2014) : 0
0

Coastal Ecosystems
Actual (2/1/2012 - 1/31/2013) : 0
Anticipated (2/1/2013 - 1/31/2014) : 0
0

:: PARTNERS

Partner Name: Northwest Fisheries Science Center (US DOC
Partner Name: Southwest Fisheries Science Center (US DOC NOAA NMFS SWFSC)

:: IMPACTS AND ACCOMPLISHMENTS

Title: **Washington Sea Grant researchers develop a better model to evaluate Pacific sardine stocks and guide fishery management decisions**

Type: accomplishment
Description:
Relevance: Pacific sardine, the second-largest federally managed West Coast fishery, is one of the most abundant fish species in the California Current. It is also important forage for many valuable and protected species. Sardine stocks have traditionally been assessed using a simple, spatially aggregated "bathtub model" that does not consider migration between regions or regional differences in age and recruitment. This has led to biased results. In 2008 the fishing industry challenged the assessments, and the Pacific Fisheries Management Council (PFMC) is now reevaluating its sardine harvest rules. More precise and accurate assessments are urgently needed.
Response: Washington Sea Grant-funded researchers used a spatially explicit model based on the 2010 sardine stock assessment to gauge the effects on population estimates of such factors as seasonal migration, spatial recruitment patterns, and the availability of fish-length data. They checked the sensitivity of their findings against the 2011 assessment and acoustic trawl surveys.
Results: The analyses showed that (a) spatially aggregated stock assessment methods can be biased when populations are spatially structured, especially when temperature affects migration, and (b) a spatially structured assessment method can reduce this bias. Researchers presented their results to the PFMC and are scheduled to lead a discussion of possible adjustments in harvest parameters at an upcoming Council meeting.
This model has been tailored to the Pacific sardine but could be modified to represent almost any mobile coastal fish stock. The simulation framework used to evaluate estimation performance could be easily modified to evaluate harvest control rules.

Recap:
Washington Sea Grant research exposes bias in current Pacific sardine assessments and develops a spatially structured model that provides more accuracy and points toward changes in harvest rules.

Comments:
Primary Focus Area – LME (SSSS)

Associated Goal: Support conservation and sustainable use of living marine resources through effective and responsible approaches, tools, models and information for harvesting wild and cultured stocks and preserving protected species (SSSS, Industry).

Related Partners:

Northwest Fisheries Science Center (US DOC, NOAA, NMFS, NWFSC)
Southwest Fisheries Science Center (US DOC, NOAA, NMFS, SWFSC)
University of Washington, School of Aquatic and Fishery Sciences, College of the Environment (UW)

:: PUBLICATIONS

No Publications Reported This Period

:: OTHER DOCUMENTS

No Documents Reported This Period

:: LEVERAGED FUNDS

No Leveraged Funds Reported This Period

WASHINGTON SEA GRANT PROGRESS REPORT

for the period 2/1/2012 – 1/31/2013

WSG Project Number: R/LME-2
Project Title: Accounting for spatial structure in stock assessments: the case of Pacific sardine

Principal Investigator and Affiliation:
André E. Punt University of Washington, School of Aquatic & Fishery Sciences

1. PROJECT OBJECTIVES (from original proposal)

The objectives of this project were to determine: 1. how much error can arise because assessments of Pacific sardine off the west coast of North America are conducted using a spatially-aggregated stock assessment method; and; and 2. can moving to a spatially-structured stock assessment reduce this error?

2. PROJECT PROGRESS

Objective 1.

Simulations using a spatially-explicit operating model based on the 2010 stock assessment were used to explore the impact of five factors on estimation performance. The five factors were: (a) seasonal migration, (b) influx of the southern subpopulation into the area which is considered to be inhabited by the northern sub-population, (c) whether or not full length and age-at-length data are available, (d) whether recruitment occurs throughout the region or just to southern California, and (e) whether or not length and age-at-length data are weighted by catches. The outcomes of these simulations were summarized by the relative error in the estimate of the spawning stock biomass in the most recent year and in the average spawning stock biomass over the last 20 years. The focus on estimate of absolute biomass is because the control rules used to set the Overfishing Limit and the Harvest Guideline for Pacific sardine are related directly to the estimate of absolute abundance for the most recent year. The relative errors were summarized using violin plots (Figure 1), and by applying ANOVA to relative errors.

The factors which have the largest influence on the performance of the estimation method are seasonal movement and how the length and age-at-length data are sampled, with seasonal movement having the largest impact on estimation ability. Spatial structuring of recruitment had a moderate impact on estimation ability, while the impact of influx of the southern subpopulation was negligible. The estimates of spawning stock biomass are negatively biased, particularly for the final year of the assessment even in the absence of migration; simulations suggest that this is because Stock Synthesis (SS) does not handle increasing stock sizes well. This suggestion was confirmed by setting up the operating model so that recruitment does not increase over the initial period of the assessment and by applying an estimation method which mimics the 2011 stock assessment, which did not use the early data. The relative errors for the estimates of spawning stock biomass for the most recent years become less negatively biased (by 10%) when there is seasonal migration which is constant over time, but more negatively biased (by ~25%) when the rate of migration depends on temperature.

Exploration of the detailed results from the simulations suggests that SS compensates for ignoring movement and spatial structure by adjusting the selectivity patterns (even though selectivity is actually the same for the Mexico and California fisheries, SS consistently estimates these to differ in the presence of spatial structure).

Objective 2

The operating model was modified for objective 2 to include generation of data from the acoustic-trawl surveys which are now part of the stock assessment, and by reparameterizing the operating model so that it is based on the 2011 rather than 2010 stock assessment. The qualitative results from this version of the operating model matched those from the operating model which was parameterized using the outputs from the 2010 stock assessment. Two of the five factors evaluated in objective 1 were included in the operating model: seasonal migration and spatial occurrence of recruitment (factors “M” and “P” respectively).

A spatially-structured stock assessment was developed using SS. This assessment divided the coast into two spatial strata at Cape Mendocino, and fitted to data separated north and south of Cape Mendocino. In addition to the parameters estimated as part of the standard stock assessment, this assessment model configuration also estimated the movement rates between the two areas (two parameters) and the proportion of the recruitment north and south of Cape Mendocino. Unlike the spatially-structured stock assessment, the selectivity patterns for the two California fleets were assumed to be same as this improved stability. Even though the spatially-structured stock assessment was mis-specified relative to the operating model (two areas instead of 10), it generally performed markedly better (Figure 2), with no evidence for bias. The estimates from the spatially-structured assessment in Figure 2 are less precise than those from the 2010 assessment (Figure 1), but more precise than the estimate from the 2011 assessment (not shown). This is primarily attributable to the spatially-structured assessment estimating more parameters than the spatially-aggregated assessment. A disadvantage of the spatially-structured assessment is that it can be unstable, occasionally (~10% of simulations) not being able to converge (Figure 2).

Results (not shown) in which the true values for movement rates or recruitment proportions were assumed to be known did not perform as well as when these parameters were estimated, but this did result in fewer instances of cases in which the model was unable to converge.

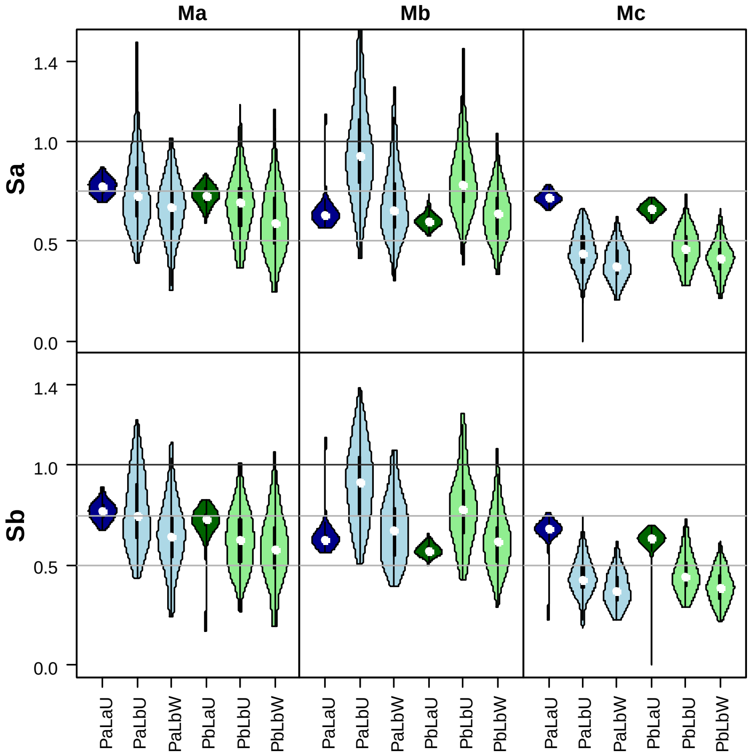

Figure 1. Violin plots of the ratio B_{est} / B_{true} for 2010. The abbreviations denote the scenarios related to the five factors.

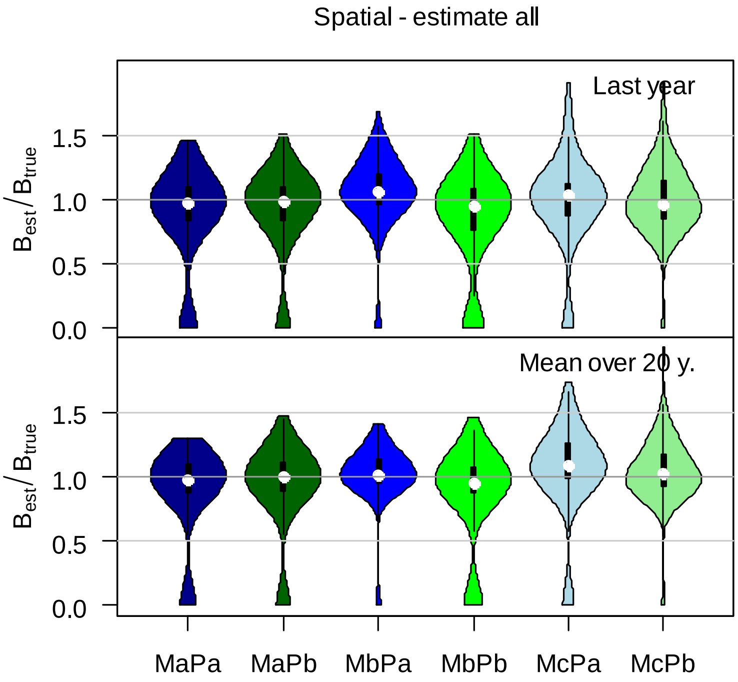

Figure 2. Violin plots of the ratio B_{est} / B_{true} for 2011 (above) and the last 19 years of the simulation (1993-2011; below), using the spatially-explicit configuration of the assessment model which estimates both recruitment allocation and movement rates. The abbreviations denote the scenarios regarding the five factors.

WASHINGTON SEA GRANT FINAL REPORT

for the period 2/1/2010 – 1/31/2013

WSG Project Number:	R/LME-2
Project Title:	Accounting for spatial structure in stock assessments: the case of Pacific sardine

Principal Investigator and Affiliation:

André E. Punt University of Washington, School of Aquatic & Fishery Sciences

Student supported by the project:

Felipe Hurtado-Ferro University of Washington, School of Aquatic & Fishery Sciences

1. PROJECT OBJECTIVES

The objectives of this project were to determine: 1. how much error can arise because assessments of Pacific sardine off the west coast of North America are conducted using a spatially-aggregated stock assessment method; and; 2. can moving to a spatially-structured stock assessment reduce this error?

2. RATIONALE

The northern subpopulation of Pacific sardine currently supports the second largest federally-managed fishery off the U.S. west coast and Pacific sardine has, at times, been the most abundant fish species in the California Current system. In addition, sardine are also forage for a wide variety of species, including those that are of considerable commercial value, such tunas and Pacific whiting, and those that are listed as overfished (e.g. rockfish spp.) or threatened (e.g. salmon and several species of marine mammals). Until the 2011 fishing year, the management decisions for sardine were based on a harvest control rule that used an estimate of the size of the age 1+ component of the population at the start of the current fishing season (the 1+ biomass) and a level of fishing mortality that depended on the temperature at Scripps Pier to determine a harvest guideline (PFMC, 1998).

The conventional conceptual model of the population dynamics of the northern subpopulation of Pacific sardine is that it concentrates in a “core” area off southern California and northern Mexico during periods of low abundance, but expands its range to the north during periods of high abundance. Historic tagging data for Pacific sardine and contemporary catch length-frequency data suggest that the large animals generally migrate northward during spring and return southward during fall.

Although several methods of stock assessment have been applied in the past to sardine, the most recent “full” assessments for sardine (Hill *et al.*, 2007, 2008, 2010, 2011) have been based on the package Stock Synthesis (SS) (Methot and Wetzel, in press). The application to sardine is based on the assumption that sardine are fully-mixed from northern Baja California to British Columbia, but that fishery selectivity differs between Mexico, California, and the Pacific Northwest. However, the review of 2007 stock assessment (PFMC, 2007) identified several issues which suggest that this assumption may be violated to some extent.

A concern with the 2008 update to this assessment (Hill *et al*., 2008) was that adding new length-frequency data for the Pacific Northwest led to a marked (44%) reduction in the estimate of the peak biomass of sardine. The review panel for that assessment was unable to understand why adding one new length-frequency sample should impact the results of the assessment so markedly, although a significant change to the selectivity patterns estimated for Pacific Northwest fishery for 2004-08, appeared to affect the estimates of recruitment for the entire period considered in the assessment.

An extension to the SS model includes features which would allow spatial structure to be captured by allowing separate sub-populations in different areas that are linked, but these features were not available for the 2007 and subsequent assessments. It is possible that allowing for these features would have improved the assessment, but, in the absence of analyses to show this, acceptance of a more complicated assessment model is unlikely.

3. METHODOLGY

The evaluation framework is outlined in Figure 1. An operating model (OM), developed and parameterized based on the 2010 and 2011 stock assessments (Hill *et al.*, 2010, 2011), is used to generate data under various hypotheses regarding population structure, and these data are used in simulated applications of the actual stock assessment procedure, which is based on the Stock Synthesis 3 package.

3.1 Operating model

The operating model is a spatially-structured population dynamics model that allows for multiple sub-stocks and regional growth. It includes the four main regions (northern Baja California, southern California, northern California, and the Pacific Northwest (PNW)) on which fishery management for the northern subpopulation is based, but is constructed with a fine spatial resolution to allow recruitment and movement dynamics to be captured adequately (Figure 2). The northern subpopulation is assumed to be composed by two growth morphs (i.e., two sub-stocks); one morph is migratory and the other is resident to the area between northern Baja California and central California. Biological parameters (natural mortality, growth, maturity and fecundity) are similar between morphs, and recruitment is allocated evenly to each morph. The southern subpopulation is not modeled explicitly. Rather, the OM allows for the occasional presence of the southern subpopulation in the modeled area (so that catches off northern Baja California and southern California sometimes include catches of animals from both the northern and southern subpopulations).

There are two types of movement among areas: diffusion and advection. Diffusion involves a fixed proportion of fish moving to adjacent areas during each time step. Advection can occur in one of two forms: seasonal movement, with a constant fraction of fish moving each time step in the same direction; and directional movement following an environmental factor (in this case sea surface temperature, SST). Here, the decision by the fish in an area whether or not to move, and in which direction, depends on the level of an external factor in the area where they are currently located and the two adjacent areas, and on a “habitat preference” function. Both diffusion and advection can be age-dependent. Following Lo *et al.* (2010), only fish larger than 200 mm are assumed to be able to migrate, which roughly translates to fish of age 3+. Sardines were assumed to be present only in the Ensenada-California area until 1990, moving into the Pacific Northwest only after this. This was done because otherwise the OM would have insufficient fish in the Ensenada-California area to support the observed catches.

The OM keeps track of the number of animals by week, age, length, and location. The population is modeled at this level of resolution not only to be able to adequately capture migration during the year, but also so that the data used for assessment purposes can be generated in a realistic manner. These data are: (a) samples of the age and length structure of the catches for each of the fisheries aggregated to “season” (6 month semester), for consistency with how such data are used in actual assessments of Pacific sardine, (b) indices of spawning stock biomass based on the daily egg production model (e.g. Lo, 2008), and (c) estimates of abundance which mimic those from the aerial (e.g., Jagielo *et al.*, 2010) and acoustic-trawl (e.g., Zwolinski *et al.*, 2012) surveys.

3.1 Stock assessment methods

3.1.1 Spatially-aggregated stock assessment

Two spatially-aggregated stock assessment configurations were explored. These assessment configurations mimicked the way the actual stock assessments were conducted for Pacific sardine in 2010 and 2011. Both assessment configurations pooled the sexes, modeled ages 0 to 15, with age 15 being a plus-group, and divided the year into two seasons. The 2010 assessment configuration started the assessment in 1983. It included six fleets (Ensenada (ENS); Southern California, season 1 (SCA1); Southern California, season 2 (SCA2); Central California, season 1 (CCA1); Central California, season 2 (CCA2); and Pacific Northwest (PNW)), each with a different selectivity pattern. Growth was assumed to change in 1991. Selectivity was assumed to change in 1991 and again in 1999 for each of the Mexico and California fisheries, and in 2003 for the PNW fleet.

The 2011 assessment configuration was simpler than the 2010 assessment configuration, with only three fleets (Mexico-California, season 1 (MexCal1); Mexico-California, season 2 (MexCal2); Pacific Northwest (PNW)), each with a different selectivity pattern. It started the assessment in 1993 (hence ignored some of early data, the sample sizes for which are small in some cases), and ignored time-varying growth, while selectivity was only assumed to change in 1999 for the two MexCal fleets.

Fishery-independent abundance estimates are available from four surveys: Daily Egg production (DEPM), Total Egg production (TEP), aerial and acoustic surveys. Each survey covers a different area and occurs at a different time during the year. The catchability coefficients are assumed to be constant over time.

3.1.2 Spatially-structured stock assessment

A spatially-structured stock assessment was also developed using SS. Its specifications matched those of the 2011 spatially-aggregated stock assessment, but it divided the coast into two spatial strata at Cape Mendocino, and fitted to data separated north and south of Cape Mendocino. In addition to the parameters estimated as part of the standard stock assessment, this assessment model configuration also estimated the movement rates between the two areas (four parameters in total), and the proportion of the recruitment north and south of Cape Mendocino (two parameters). Unlike the spatially-structured stock assessment, the selectivity patterns for the two MexCal fleets were assumed to be same as this improved stability. The number of surveys for the spatial model is seven rather than four, because the DEPM, TEP and acoustic surveys are split north and south at Cape Mendocino. However, the number of survey selectivity and catchability parameters that are estimated remains the same as for the spatially-aggregated model because the surveys that are split by area are assumed to have the same catchability and selectivity parameters (e.g., the acoustic survey for the southern area is assumed to have the same catchability and selectivity, as the acoustic survey for the northern area).

3.1.3 Scenarios and performance measures

Simulations using a spatially-explicit operating model based on the 2010 stock assessment were used to explore the impact of five factors on estimation performance. The five factors were: (a) seasonal migration, (b) influx of the southern subpopulation into the area which is considered to be inhabited by the northern sub-population, (c) whether or not full length and age-at-length data are available, (d) whether recruitment occurs throughout the region or just to southern California, and (e) whether or not length and age-at-length data are weighted. The simulation scenarios were based on combinations of assumptions related to each of these factors (the letters in parentheses are used to identify the scenarios):

1) Seasonal migration (M):
    a. Sardines do not migrate, but are uniformly distributed along the West Coast.
    b. Sardines have 'constant' seasonal migrations, of the same magnitude and direction every year.
    c. Sardine movement is a function of sea surface temperature. The rate of movement is constant.
2) Southern subpopulation (S):
    a. No influx from the southern subpopulation.
    b. The southern subpopulation appears into the ENS area every summer (during July). The age and length composition of the southern subpopulation is assumed to be the same as that in the ENS area.
3) Persistence of sardine in the PNW (P):
    a. Sardines only recruit to the area between Ensenada and Central California.
    b. Sardines recruit uniformly across the entire West Coast every year after 1990.
4) Length-composition data (L)
    a. Full length- and age-composition data are available for the entire period considered in the assessment. This is implemented by assuming that compositional data are sampled at every time step and area where catches occur, and that a large number of fish are collected in each sample (1000 fish per sample).
    b. Availability of length-composition data is same as that in reality.
5) Composition sampling:
    a. Uniform sampling (U). All areas, weeks and fleets are sampled with the same intensity.
    b. Weighed sampling (W). Areas or weeks with higher catches are sampled more intensively.

The outcomes of these simulations were summarized by the relative error in the estimate of the spawning stock biomass in the most recent year and the average spawning stock biomass over the last 20 years. The focus on the estimate of absolute biomass is because the control rules used to set the Overfishing Limit and the Harvest Guideline for Pacific sardine are related directly to the estimate of absolute abundance for the most recent year. The relative errors were summarized using violin plots, and by applying ANOVA to them.

4. MAJOR FINDINGS

4.1 Performance of spatially-aggregated assessment configurations

The factors which have the largest influence on the performance of the estimation method were seasonal movement and how the length and age-at-length data are sampled, with seasonal movement having the largest impact on estimation ability. Spatial structuring of recruitment had a moderate impact on estimation ability, while the impact of the influx of the southern subpopulation was negligible. The estimates of spawning stock biomass are negatively biased, particularly for the final year of the assessment (Figure 3), even in the absence of migration; simulations suggest that this is because Stock Synthesis (SS) does not handle increasing stock sizes well. This suggestion was confirmed by setting up the operating model so that recruitment does not increase over the initial period of the assessment and by applying an estimation method which mimics the 2011 stock assessment, which did not use the early data. The relative errors for the estimates of spawning stock biomass for the most recent years become less negatively biased (by 10%) when there is seasonal migration which is constant over time, but more negatively biased (by ~25%) when the rate of migration depends on temperature.

The estimates of selectivity-at-length for the Mexico and California fisheries vary among fleets even when the true selectivity patterns for those fleets are the same. This is because the estimated selectivity patterns for the fleets are compensating for ignoring movement and spatial structure by adjusting the selectivity patterns (even though selectivity is actually the same, SS consistently estimates these to differ in the presence of spatial structure).

4.2 Performance of spatially-structured assessment configurations

Even though the spatially-structured stock assessment was mis-specified relative to the operating model (two areas instead of 10), it generally performed markedly better than the spatially-aggregated stock assessment, with no evidence for bias (Figure 4). The estimates from the spatially-structured assessment in Figure 4 are less precise than those from the 2010 assessment (Figure 3), but more precise than the estimate from the 2011 assessment (results not shown). This is primarily attributable to the spatially-structured assessment estimating more parameters than the spatially-aggregated assessment. A disadvantage of the spatially-structured assessment is that it can be unstable, occasionally (~10% of simulations) not being able to converge (Figure 4). Ignoring the simulations which did not converge, the spatially-structured stock assessment led to estimates with lower root mean square error than the 2011 assessment for all six cases in Figure 4 and lower root mean square error than the 2010 assessment for all but the case MbPb (constant migration and recruitment over the entire coast).

Results (not shown) in which the true values for movement rates or recruitment proportions were assumed to be known did not perform as well as when these parameters were estimated (higher root mean square errors), but this did result in fewer instances of cases in which SS was unable to converge.

5. DISCUSSION, RECOMMENDATIONS AND NEXT STEPS

Almost all fisheries stock assessments (implicitly) assume that the population being assessed constitutes a single homogeneous population or that the fishery is random with respect to the distribution of the population. These assumptions will, however, be violated to a greater or lesser extent for all stocks. This study, along with several previous studies (e.g., Punt, 2003; Cope and Punt, 2011; McGillard, 2012) have shown that ignoring spatial structure can lead to biased estimates of abundance.

This study confirms that the common practice of representing spatial areas as fleets can reduce the impact of the bias caused by ignoring spatial structure, but that this practice is not sufficient to fully correct for the effect of spatial structure. This is particularly the case when migration rates are changing over time, as appears to the case for Pacific sardine, the distribution of which has changed over the period considered in the assessments used by the PFMC. A further concern with the “fleets as areas” approach not considered in this study is how to choose fleets. A larger number of fleets would better represent spatial structure (and hence reduce the bias due to spatial structure), but this would be at the expense of lower precision because more parameters need to be estimated. Comparisons between the actual (more complex) 2010 and the (simpler) 2011 assessments for Pacific sardine indicates that the latter assessment is more stable (K. Hill, pers commn). Thus, while this study supports the “fleets as areas” approach as a basis for assessments, including for that of Pacific sardine, further investigation of the properties of the approach are warranted.

The estimates of selectivity differed among fleets when the “fleets as areas” approach was applied because selectivity as estimated during the assessment mimicked the combined effects of selectivity and availability. One consequence of this result is that assuming selectivity for multiple fleets to be the same owing to the use of similar gear (and hence reducing the number of estimated parameters) may lead to biased results, even though the assumption that selectivity for the fleets concerned is the same is true. It is therefore recommended that model selection methods should be applied before selectivity for fleets which should have similar selectivity is assumed to be the same.

The spatially-structured assessment model led to markedly lower bias when applied to data generated from the OM for all scenarios. However, this assessment model had problems with convergence (Figure 4). Further development of SS to detect and correct for convergence problems will enhance the likelihood that a spatially-structured assessment will vastly outperform a spatially-aggregated assessment.

Fixing rather than estimating parameters related to movement and recruitment did not enhance estimation performance, even when the parameters were set to the correct values. Although this may seem surprising, it is likely a consequence of the spatial structure underlying the OM not matching that of the spatially-structured assessment model exactly. However, the improvement in performance is sufficient that a spatially-structured assessment model of the form tested here should be introduced into the assessment process.

6. STUDENTS SUPPORTED

1. Mr Felipe Hurtado-Ferro, PhD student, University of Washington, thesis title "Management of small pelagic fishes"

7. REFERENCES

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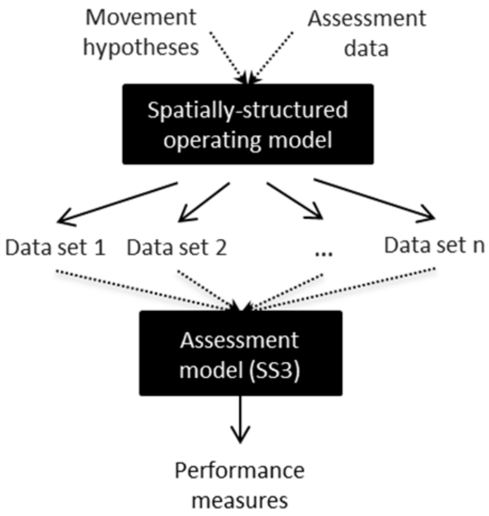

Figure 1. Schematic representation of the stock assessment evaluation framework

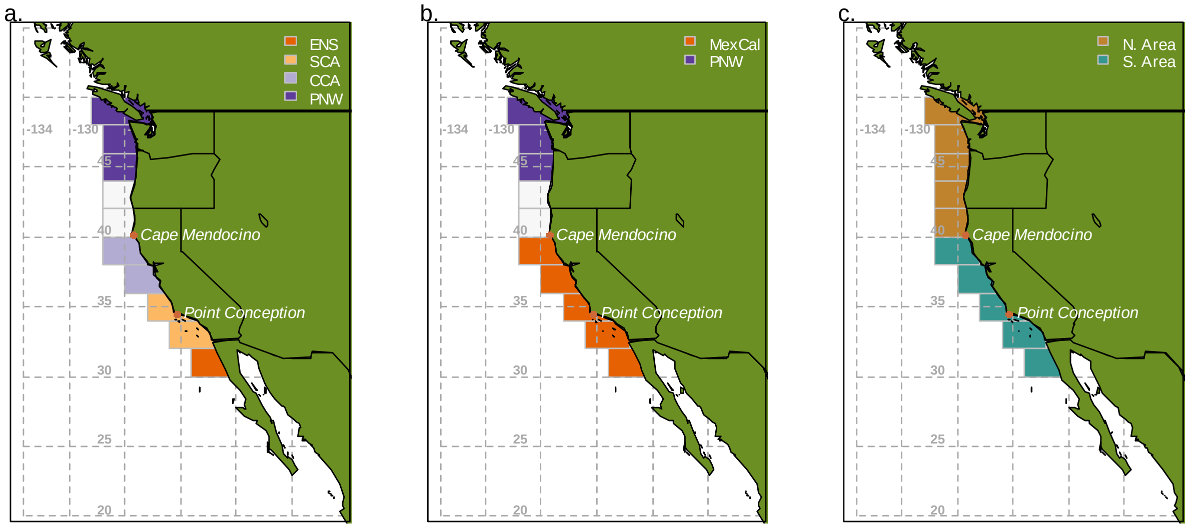

Figure 2. Spatial configuration of the operating and assessment models. a) Fleet distribution in the OM and 2010-like assessment (i.e. configured with 6 fleets); b) fleet structure for the 2011-like and spatially-explicit assessments (i.e. configured with three fleets); and c) area definition for spatially-explicit configuration of the assessment model.

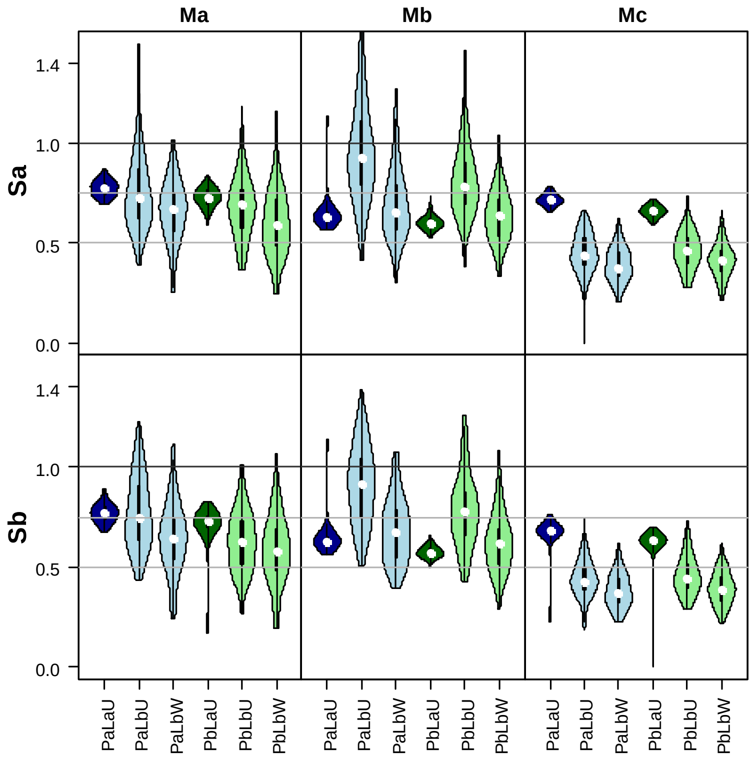

Figure 3. Violin plots of the ratio B_{est} / B_{true} for 2010 when the assessment is based on the 2010 configuration of the assessment. The abbreviations denote the scenarios related to the five factors.

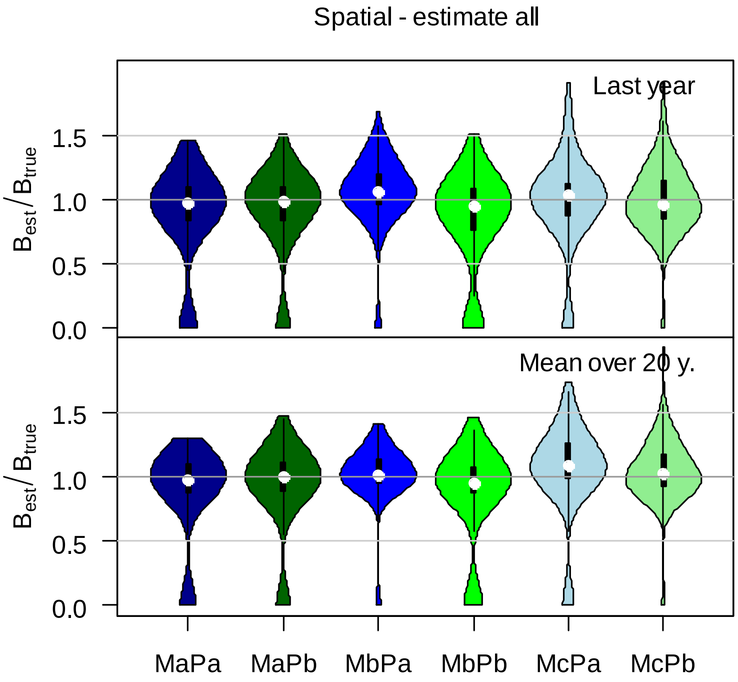

Figure 4. Violin plots of the ratio B_{est} / B_{true} for 2011 (above) and the last 19 years of the simulation (1993-2011; below), using the spatially-explicit configuration of the assessment model which estimates both recruitment allocation and movement rates. The abbreviations denote the scenarios regarding the five factors.