CAPAM workshop on development of spatial stock assessment models: Abstracts

Defining Spatial Structure

Defining Spatial Structure of Fisheries

Steven X. Cadrin

Typical fishery stock assessments assume a unit stock (i.e., population dynamics are internally determined) and a dynamic pool (i.e., all members of an age or length class have homogeneous vital rates). However, all populations and fisheries have some spatial heterogeneity, many have mixed stocks, some single populations contribute to multiple fishery management units, and some management units include multiple distinct populations. Stock identification involves the recognition of reproductively isolated populations or self-sustaining and demographically independent population components. Stock identification methods have advanced in recent decades as a result of technological developments and have evolved toward an interdisciplinary analysis in which putative groups are determined from spatial patterns of fishery and fishery-independent information, geographic variation is informed by genetic and phenotypic characters, and connectivity is inferred from artificial and natural tags. Advances in stock identification methodologies have detected much greater spatial structure than assumed in many stock assessments. Although some spatially-simple models perform well for informing fisheries management, other spatial patterns justify revised management unit boundaries, spatially-structured stock assessment, routine stock composition analysis, or spatial management procedures. Among these options, revised management units have considerable policy implications (e.g., jurisdictions and catch allocations), and spatially-structured stock assessment can be challenging, particularly for estimating time-varying movement rates among areas. A promising approach to accounting for spatial structure is to develop spatially-complex assessment models that condition operating models for testing the performance of alternative spatial management procedures. As advances in stock identification methods are applied to more fisheries resources, the trend in detecting spatial complexities is expected to continue, so guidance on best practices in spatially-structured stock assessment models is needed.

Identifying spatial scales and synchrony in dynamics with empirical dynamic modeling from the CalCOFI ichthyoplankton survey

Peter Kuriyama

Empirical dynamic models are a group of equation-free models that have proven to provide accurate out-of-sample predictions and identify causal relationships in marine and terrestrial ecosystems. Here, we apply simplex, smaps, and time delay embedded Gaussian processes to the CalCOFI dataset, an ichthyoplankton survey in the California current which began in 1951, to identify synchrony in the dynamics of species and groups of species. Specifically, we seek to identify the spatial scales of synchronous dynamics and identify regime shifts in real time.

Distribution areas of Jack Mackerel (Trachurus murphyi) in the South Pacific

Ricardo Oliveros-Ramos, Enrique Ramos-Vasquez, Arnaud Bertrand, Jorge Csirke

South pacific Jack mackerel (Trachurus murphyi) has an ocean-scale distribution range, from the equator to the austral region of Chile along the South American coastline, and from the coast of South America to New Zealand and Tasmania. South Pacific Fisheries Management Organisation (SPRFMO) is concerned to the conservation and management of Jack mackerel in the high seas, relying on estimates of biomass and fishing pressure based on the assumptions on population dynamics, including population structure. Several hypotheses have been proposed for jack mackerel population structure, from a single population up to several discrete populations; while recent studies show a pelagic metapopulation structure is the more likely. However, still no definitive answer has been given and the uncertainty associated to its population structure still hampers management. In this work we model the spatial distribution of Jack mackerel in the South Pacific in order to analyze the spatio-temporal variability of the habitat suitability and use it to dynamically classify stable habitats and transition zones. This classification uses metrics of the stability of the habitat (mean habitat quality, interannual stability, seasonal stability, strength of the seasonality and impact of extreme events) to identify similar areas by cluster analysis. We identified three stable sub-areas of distribution: one main sub-area with high habitat suitability and high seasonal and interannual stability off the Chilean coast (25ºS-41ºS) extending through the "jack mackerel belt" up to 134ºW; and two sub-areas with high habitat suitability but low seasonal and interannual stability off Peru and New Zealand coasts. The dynamics of the transition zones between these three sub-areas may be related to migration exchanges and periods of partial isolation, supporting the metapopulation hypothesis. The implications of these results for the stock assessment and management are discussed.

A Multivariate Tree-based Method for Exploring Stock Structure in Multiple Data Sets

Cleridy E. Lennert-Cody, Mark N. Maunder, Carolina Minte-Vera, Haikun Xu, Juan Valero, Alexandre Aires-da-Silva, Jon Lopez

Stock structure can be explored through the analysis of different types of data including catch and effort data and morphological characteristics (e.g., length or weight of individuals). Different measures of variability may be preferable for different data types. For morphometric data summaries, such as frequency distributions of size, it is preferable that the measure of differences between size frequency distributions put more weight on discrepancies of those size intervals with the greatest proportion of observations, such as is done with the Kullback-Leibler divergence. In contrast, summaries of catch data, which may focus on differences in CPUE trends, can be quantified with squared error-type measures. Tree-based methods have the advantage that it is relatively easy to implement different loss functions for different data types. These methods also have the ability to find similar structure in multiple data types by utilizing information on competitor splits. In this presentation we illustrate the multivariate tree-based methodology with longline and purse-seine data for bigeye tuna in the eastern Pacific Ocean and discuss potential methodological improvements.

Spatial structure assumptions for the population dynamics model of bigeye tuna in the eastern Pacific Ocean

Carolina Minte-Vera, Cleridy Lennert-Cody, Haikun Xu, Juan Valero, Mark Maunder, Kurt Schaefer, Jon Lopez, Alexandre Aires-da-Silva

The current model used to assess the stock of bigeye tuna in the eastern Pacific Ocean (EPO) is a "one area model", that assumes a single stock distributed homogeneously and well mixed throughout the distribution of the fisheries catching bigeye tuna. This model has an apparent "two-regime" pattern in recruitment, with recruitment estimates after mid-1990 about double on average those of the previous period, coinciding with the expansion of the purse-seine fleet targeting tuna aggregations associated with fish aggregating devices (FADs). This might be caused primarily by spatial misspecification of the model: the increase in purse-seine catch in a longitudinally wide equatorial area is not accurately reflected in a reduction in the standardized Japanese longline catch per unit of effort (CPUE), used as an index of abundance in the stock assessment. This may be due to relatively restricted movements and limited dispersion of bigeye leading to local depletion, and to the fact that the longline CPUE indices used in the stock assessment measure abundance over a different area than that where the increased purse-seine catch occurred. Also, extensive tagging studies utilizing both conventional and archival tags have shown evidence for localized dynamics for the bigeye tuna stock(s) in the EPO. This evidence indicates that a spatial model, with regional structure and movement among regions, might be more suitable to describe the population dynamics of bigeye tuna in the EPO. We postulate spatial structure assumptions for the population dynamics model of bigeye tuna in the EPO based on analyses of the tagging data, as well as utilizing the longline and purse-seine fisheries CPUE and size composition data using a multivariate tree-based methodology.

Movement: data and theory

The primacy of space: movement theory, past, present, and future

Andrew Hein

The movement of organisms from one place to another plays an important part in virtually all ecosystems in which it has been studied. In this talk, I will discuss theoretical developments toward an understanding of animal movement and how it relates to ecological dynamics. The current state of movement theory suggests the value in revisiting the spatial origins of population dynamic models, and new directions for research that could allow us to more fully integrate movement into an understanding of population and ecosystem dynamics.

Telemetry Analysis of Highly Migratory Species

Chi Hin (Tim) Lam and Benjamin Galuardi

Fish stocks and breeding populations of sea turtles and marine mammals are often classified according to geographic range and habitation. While telemetry data is an essential tool for determining habitat utilization and behavior, it also presents unique challenges when applied to highly migratory species. We focus on these aspects through exemplary uses of telemetry data within the constraints of geolocation techniques. The scale at which inferences may be made is related to the animal physiology and behavior, limitations of tagging technology, data availability and assumptions and processes of geolocation techniques. We focus especially on state space models as a link between analysis of different data types and their ability to derive behavior and utilization while highlighting recent developments and management applications. Lastly, we highlight the potential pitfall of limited observational capabilities, even with the latest telemetry technologies, and suggest integrated analyses with fisheries dependent data as a way to mitigate this limitation.

Estimating the movement rate of bigeye tuna in the eastern Pacific Ocean

Haikun Xu, Cleridy Lennert-Cody, Mark Maunder, Carolina Minte-Vera, Juan Valero, Kurt Schaefer, Dan Fuller, John Hampton, and Alexandre Aires-da-Silva

Between-stock movement rate is a key input to spatially-explicit stock assessment models. It can be quantitatively estimated either internally inside the stock assessment model or externally based on available tagging data. Here, we present the estimated movement rate of bigeye tuna in the eastern Pacific Ocean (EPO) and the methodology and assumptions on which the estimation is based. Specifically, we estimate an east-west movement rate externally using conventional tagging data for bigeye tuna from deployments in the equatorial region between about 10°N and 10°S and at about 95°W during 2000-2006 and at about 140°W during 2008-2012. A mark-recapture model was built for bigeye tuna in the equatorial EPO to estimate the movement rate across the proposed longitudinal stock boundary of 110°W via the maximum likelihood estimation approach. The mean eastward movement rate across 110°W is estimated to be 16% per quarter and mean westward movement rate across 110°W to be less than 2% per quarter. These estimates should be applied to immature bigeye tuna only as most of the fish recaptured are significantly smaller than the length at 50% maturity in the EPO of 135 cm. To evaluate the movement patterns of mature bigeye tuna, we investigate the distribution of recapture locations for larger individuals in the conventional tagging data. Also, we analyze the spatiotemporal dynamics of catch rate data obtained from the Japanese longline fishery that targets large bigeye tuna. The spatiotemporal pattern in longline catch rate suggests that some mature bigeye tuna, if not all, may have a seasonal movement behavior within the EPO. However, we cannot rule out the possibility that the pattern is due instead to the seasonality in catchability.

Spatial stock assessment models

Spatial stock assessment methods: A review of current approaches and assumptions

André E. Punt

Spatial stock assessments have been developed to address violations of the dynamic pool assumption that the region to be assessed contains a single homogeneous stock. The possibility of such violation is often evident in data that suggest different trends in abundance among areas that cannot be explained simply by the fishing history or differences in the age- / size-structure among areas. Currently, most stock assessments account for spatial structure using the 'areas-as-fleets' approach in which fishery or survey selectivity is assumed to differ spatially. However, several simulation studies suggest that adopting spatial approaches to stock assessment will improve estimation performance compared to the areas-as-fleets approach and ignoring spatial structure when conducting stock assessments, although at the cost of a larger number of estimable parameters. Spatial approaches to stock assessment and the provision of management advice have been available since the 1950s, but spatial stock assessments only became adopted for management purposes in the 1990s, with the widespread adoption of the "integrated approach" to stock assessment, which allowed the use of multiple data sets for parameter estimation. The number of spatial stock assessments is now increasing rapidly. This paper outlines some of the key decisions that need to be made when conducting a spatial stock assessment (number of areas, how to model recruitment, movement, and dispersal, and model parameterization) and how it is possible to implement these suggestions in the world's most popular integrated approach to stock assessment, Stock Synthesis.

Consequences of misspecifying population structure within spatially explicit stock assessment models

Katelyn Bosley, Aaron Berger, Jon Deroba Daniel Goethel, Dana Hanselman, Brian Langseth, Amy Schueller

Contemporary spatiotemporal assessment models have the ability to inform fine-scale processes and spatial management for complex and heterogeneous populations. Spatially explicit assessment models can improve estimates of population productivity by simultaneously modeling individual spawning components (along with connectivity among them) instead of aggregating data and parameters across multiple reproductive units. Although spatial models may provide a more realistic representation of the true population dynamics, few studies have evaluated the potential risk associated with incorrect assumptions regarding population structure and connectivity. We simulated the dynamics of a long-lived demersal species (sablefish) under different assumptions of population structure including panmictic, single population with spatial heterogeneity, and metapopulation. We then applied a spatially explicit, tag-integrated assessment model to simulated observations where the model either correctly or incorrectly assumed the simulated underlying spatial structure. Results from this study elucidates how incorrect assumptions regarding population structure can influence the estimation of key parameters used in fisheries management and what modal parameterizations are robust to variability in the true underlying population dynamics. In many cases, spatial models are advantageous because the model outputs are generated at scales relevant to important sources of variability (e.g., biology or fleet dynamics), and therefore they can inform spatial management even if incorrectly specified, providing that adequate data is available (e.g., tag-recapture or high quality catch-at-age information).

Simulation testing stock assessments of spatially-structured Atlantic bluefin tuna stocks

Molly R. Morse, Lisa A. Kerr, Steven X. Cadrin

Accounting for patterns of movement and mixing in stock assessment of highly migratory species is important for managing these fisheries sustainably. Despite the growing wealth of information characterizing mixing between the western and eastern populations of Atlantic bluefin tuna (Thunnus thynnus), the stock assessment methods on which their management is based do not explicitly account for this critical aspect of stock structure. Simulation modeling is a useful tool for evaluating the consequences of spatial structure and connectivity among fish stocks on stock assessment outcomes. We used simulation to test the performance of the single-stock virtual population analysis models and reference points currently used to manage Atlantic bluefin tuna fisheries. Pseudodata were generated from a spatially-explicit operating model that incorporated movement to emulate mixing of western and eastern bluefin populations. Model misspecification of spatial structure caused estimation models to frequently produce biased estimates of recruitment and spawning stock biomass. The western estimation model was particularly sensitive to stock mixing, and biased estimates resulted from the model's inability to capture a net subsidy of the eastern population into western stock areas and fisheries. Models were better able to predict the size of mixed-population stocks than genetically-distinct populations, suggesting that model predictions may be more effective for informing short-term trends in the resources available to fisheries than for implementing management decisions required for conservation of populations. Determination of relative stock status from fishing mortality-based reference points performed better than absolute estimates: stock status was correctly identified 94% of the time for the western stock and 85% of the time for the eastern stock. The results of this study suggest that stock mixing should be more explicitly considered in stock assessment of Atlantic bluefin

tuna, and underscore the importance of testing stock assessment models and communicating their biases and limitations to managers.

The Spatial Population Model software for management support

Sophie Mormede, Alistair Dunn, Steve Parker

The Spatial Population Model (SPM) is a bayesian age-structured population model software. It allows the modelling of multiple species in a large number of spatial cells. Movement can be parameterized as individual movement estimates, diffusion processes, or driven by preference functions, all of which are estimable. SPM has been used to estimate the likely population distribution of Antarctic toothfish in the Ross Sea region and estimate the likely bias of the single area stock assessment. It was also used to simulate the impact various spatial management strategies on the stock and the future catch. Other applications have included multi-species spatial population models and models of other species such as deepwater snapper in a seamount habitat. The use of input parameter files makes this software a useful tool to investigate spatial population dynamics.

A simulation comparison of spatiotemporal and spatially-implicit size-structured models

Jie Cao, James T. Thorson, André E. Punt, Cody Szuwalski

Characterizing population distribution and abundance over space and time is central to population ecology and conservation of natural populations. Exploited populations exhibit heterogeneous and complex spatial structure, and this heterogeneity is rarely modeled explicitly in resource assessments. However, population models that do not explicitly model spatial heterogeneity (called “spatially-implicit models” here) have several limitations, including the potential for vulnerability to exploitation

(“selectivity”) to vary among sizes/ages over time related to changing spatial distributions. We therefore develop a spatiotemporal model for estimating population dynamics at a fine spatial scale, demonstrated for two species with different types of life history, i.e., snow crab in the Eastern Bering Sea and northern shrimp in the Gulf of Maine. We compare the spatiotemporal model with a spatially-implicit model and systematically evaluate the spatiotemporal model based on simulation experiments. We show that the spatiotemporal model can recover spatial patterns in population and exploitation pressure as well as provide unbiased estimates of spatially-aggregated population quantities. The spatiotemporal models also implicitly account for individual movement rates, and can outperform spatially-implicit models by accounting for time-and-size varying selectivity caused by spatial heterogeneity. We therefore conclude that spatiotemporal modelling framework is a plausible and promising approach to address the spatial structure of natural resource populations, which is a major challenge in understanding population dynamics and conducting resource assessment and management.

Incorporating spawn surveys in a semi-spatial stock-recruitment model

John T. Trochta, Alec MacCall, David W. McGowan, and Trevor A. Branch

Capturing the spatial structure of spawning behavior may address part of the large uncertainty in stock assessments of fish populations that reproduce at multiple sites. For some species, such as Pacific herring, the location, size, and frequency of spawn events are surveyed over time and provide a record of changes in the spatio-temporal distribution of spawning sites. We consider incorporating this information into a stock-recruitment model with the aim of improving predictions of recruitment. Assuming a Ricker functional form, the stock-recruit relationship is modified as follows: $R_{tot}=\alpha B_{tot} e^{(-\beta P B_{tot})}$, where P is an annual index derived from conventional diversity indices to describe the average proportion of biomass at each spawning site, B_{tot} is the total parental biomass, and α and β are the standard density independent and density dependent terms respectively of the Ricker function. Since our approach does not recognize each spawning site individually, but a summary statistic with information on the number of occupied sites and the relative abundances of spawners at those sites, we call this a "semi-spatial" stock-recruitment model. I will discuss the parameterization of the semi-spatial model along with an investigation of its utility using a simulation study and its application to Pacific herring in Prince William Sound, Alaska.

State Space Models for salmon: What can be learned and applied to marine species?

Rishi Sharma, Martin Liermann and Tom Cooney

We demonstrate a spatial assessment model to evaluate the effects of habitat, hydro and ocean survival on four endangered spring Chinook salmon populations in the upper Columbia River using a state space model. The process model tracks juveniles through three different freshwater life-stages with two alternate pathways for each population. Ocean residence is modeled using time and age varying maturation rates with fixed age specific survivals. The observation model uses year and population specific estimates of abundance and survival for different stages based on in river traps, weir counts and mark-recapture experiments. With these populations, movement in space through time is heavily confined by the species life-history and the riverine network during their freshwater residence. This makes it possible to assign survivals and abundances to specific pathways and parameterize relatively complex models.We contrast this situation with many marine species of interest, where movement is less constrained and well understood. For these populations, assumptions about the distribution and movement of fish are more difficult to construct and justify. This makes interpretation of tagging data more difficult and the model results more sensitive to uncertainty in these assumptions.

Integrating tagging data

Where Do You Think You're Going? Improving the Spatial Dynamics of Stock Assessment Models by Incorporating Tagging Data

Daniel R. Goethel and Aaron M. Berger

Spatial stock assessment models are valuable tools that support fisheries management decisions at a scale amenable to capturing key spatial processes. By accounting for spatial population structure and connectivity across life stages, spatial models can lead to a better understanding of a species' reproductive resilience. The simultaneous growth of integrated assessment models and advanced tagging technology has provided a unique opportunity to incorporate tagging data sets directly within spatial assessment models. Information from tagging data can help inform assessment estimates of growth, abundance, mortality, and movement rates. We first provide a literature review highlighting the progress in tag-integrated modeling since the 2007 IATTC workshop on 'Using Tagging Data for Fisheries Stock Assessment and Management Strategies'. Although there has been increased implementation of tag-integrated models over the last decade, their use as the basis of management advice remains limited, partially owing to the perceived need for long timeseries of tag data with experimental designs defined specifically for end use in assessment models. Second, we simulation test a generalized tag-integrated model to explore how tagging experimental design can impact the reliability of model estimates. Simulations demonstrate how life history, spatial population structure, and movement dynamics influence the need for auxiliary data in spatial models, and illustrate that tag-integrated models can be robust to imperfect tagging data. Compared to spatial models that do not incorporate tagging information, tag-integrated models provide improved estimates of many population parameters. Additionally, tag-integrated models offer more realistic and accurate spatial dynamics (e.g., by reliably estimating time- and age-varying movement), which can help overcome many of the pitfalls (e.g., incorrectly specified and poorly estimated movement parameters) associated with spatial assessment models.

Simulation Analysis of a Spatially Explicit Tag-Integrated Catch-at-Age Model that Estimates Natural Mortality and Reporting Rate and Application to Lake Erie Walleye

Matthew Vincent, Travis Brenden and James Bence

The influence of model complexity on Integrated Tagging and Catch-at-Age ANalysis (ITCAAN) parameter estimation is less studied for populations exhibiting natal homing than models that assume intermixing metapopulations. We used simulations to investigate the bias and precision of ITCAAN model estimates under varying levels of movement and the degree of similarity in population productivities. The operating model simulated the dynamics of four populations with natal homing that intermixed during periods of harvest based on dynamics of Lake Erie walleye (Sander vitreus) populations. Our results suggest that when high quality tagging data are available, ITCAAN models are able to simultaneously estimate movement rates, natural mortality and tag reporting rates. However, ITCAAN models may have difficulty estimating individual population abundances under certain movement rates when population productivities are vastly different. Data from Lake Erie walleye were fit in an ITCAAN model that

estimated movement, natural mortality, and reporting rates. Model results were sensitive to the assumed weighting of the tag-recovery data and assumptions regarding tag reporting rates.

Using spatio-temporal models of tagging data to deal with incomplete mixing

Mark N Maunder, James T Thorson, Haikun Xu

Tagging data is key to the development of spatially-structured stock assessment models. Unfortunately, the practicalities of tagging fish inhibit the implementation of tagging designs, and the tagged fish do not completely mix with the population. As a convenient fix, the initial recoveries are often "ignored" for a given period to "ensure" complete mixing. However, this is not optimal and alternative approaches should be investigated to deal with tag mixing, particularly for short lived or slow mixing stocks. Here we describe an initial attempt to account for mixing based on spatio-temporal models and discuss possible improvements. The tagged population is modelled over time as an advection-diffusion process. The total population is modelled using a hierarchical spatio-temporal model based on a Gaussian random field. The predicted recoveries are then compared to the observed recoveries based on the exploitation rates using a likelihood function where the spatially specific exploitation rates are equal to the catch divided by the predicted total abundance. The model is implemented in Template Model Builder (TMB) and integrates across the advection-diffusion process and the Gaussian random field. Parameters are estimated using maximum likelihood. Possible improvements include: 1) removing tag recoveries from the tagged population; 2) using the advection-diffusion process to move the total population; 3) removing catch from the total population; 4) alternative likelihood functions; 5) including size information. The approach is illustrated using data for tropical tunas in the eastern Pacific Ocean and discussed in terms of designing tagging programs.

Other information

Incorporating mixed stock information into assessment and management

Lisa Kerr

There have been notable advances in stock identification methods and a proliferation of applications in recent decades, with many results relevant to fisheries assessment and management. In many cases, application of stock identification methods has revealed inconsistencies between the spatial structure of biological populations and the definition of stock units used in assessment and management. Despite this increasing number of applications, there are few examples where this approach has been integrated into the assessment and management of stocks. Mixed stock analysis using an established stock identification technique can enable quantification of the origin of fish across broad spatial and temporal scales. There are a range of approaches for integrating mixed stock information into the assessment and management process, including: 1) revising data to inform assessment, 2) integrating information into assessment, and 3) changing the scale of the stock assessment and/or management. Several case studies will be highlighted that demonstrate these approaches. Alignment of biological and management units requires continual monitoring through the application of stock identification methods in conjunction with responsive management to preserve biocomplexity and the natural stability and resilience of fish species.

1) Eastern and Western Baltic Atlantic cod, and 2) Western Baltic spring spawning herring and North Sea autumn spawning herring, and 3) Western and eastern bluefin tuna.

We describe approaches that are currently being applied to improve the assessment and management process for marine fish in situations where complex spatial structure has led to an observed mismatch between the scale of biological populations and spatially-defined stock units.

Information needs: 1) spatial and temporal scale of sampling.

Multiple approaches exist for integrating these dynamic processes into stock assessment modelling and management; however, it is still rare that assessments address. For example, mixed stock composition information can be used to revise data inputs to stock assessment (e.g., assign catch to its natal origin), potentially resulting in more accurate estimates of abundance and fishing mortality. Furthermore, information from data storage and satellite tags can provide information on fish movements between regions which can be directly integrated into assessment models to account for stock mixing. Finally, synthesis of interdisciplinary stock structure information can be used to informed spatial and temporal management measures aimed at conserving a unique population or can be used to redefine harvest stock units.

A spatially-explicit population dynamics and stock assessment model driven by environmental variables

Patrick Lehodey and Inna Senina

The Spatial Ecosystem And Population Dynamics Model (SEAPODYM) provides spatially explicit representation of population dynamics integrating relationships between fish movement and the environmental variables, and includes a robust estimation approach of population dynamics and fisheries parameters. Several types of data can be included in the Maximum Likelihood Estimation approach: catch, fishing effort and size frequencies of catch from fisheries or research surveys as in standard stock assessment models, but also tagging data, acoustic biomass estimates, and eggs and larvae densities.

These data can be assimilated at the resolution of the model, typically monthly 1 or 2-degree squares for basin scale configurations. The model has been used for several species of tuna, swordfish, and the South Pacific Jack mackerel. Preliminary work was also conducted for sardines and anchovies.

Since the population dynamics is driven by environmental mechanisms the distribution of all cohorts from larvae to oldest adults are predicted everywhere based on the global parameterization. Classical metrics for stock assessment can be provided from the simulations and fishing impacts discriminated from environmental variability. The impact of climate change on the populations dynamics can be investigated using projections of environmental forcings generated by IPCC Earth Climate models. The interest of this new approach is illustrated with various applications and studies.

Scaling factors for multi-region stock assessments, with adjustments for ocean area

Simon Hoyle and Adam Langley

Stock assessments may be spatially structured, with regions that contain separate but linked subpopulations. In such multi-region assessments we must determine the relative abundances among regions. Regional scaling, which has been used since 2005 in tuna assessments, estimates the abundance distribution from regional catch rates and areas. We describe the method and explore potential improvements to the current practice. Supported improvements included using cell ocean areas in scaling calculations; adjusting statistical weights in the standardization model based on the density of samples; including fleet effects in the standardization model; and using a region-season interaction term in the standardization model rather than a year-season term.

Applications

Spatially-Structured Tuna Stock Assessments in the Western and Central Pacific Ocean

John Hampton and Matthew Vincent

Spatially-structured stock assessments for tuna in the western and central Pacific Ocean (WCPO) were first developed in the late 1990s, using the integrated stock assessment software MULTIFAN-CL. The first application was for South Pacific albacore (Fournier et al. 1997), motivated initially by the clear spatial segregation of the stock by size (increasing size from south to north), and to allow better estimates of interaction among spatially-separated fisheries. Spatially-structured assessments have since been applied to the other main tuna stocks in the WCPO – skipjack, yellowfin and bigeye tuna. The spatial structure of these assessments has evolved over time in response to increased awareness of various factors to consider when specifying spatial configuration. These factors include management jurisdictions, spatial variation in biological characteristics, distribution of fisheries, and distribution and resolution of available data sources, notably tag-recovery and size frequency data. Movement estimation is a critical feature of these models. While tagging data are usually influential, other data types in the assessment are also important; we present likelihood profile analyses that demonstrate the relative impact of different data types on movement estimation across WCPO tuna assessments.

Incorporation of spatial structure in assessment models can provide benefits over models that assume spatial homogeneity; however there are still some limitations to this approach with currently available modelling techniques. Plans for further development of the MULTIFAN-CL software to address some of the current limitations will be discussed.

A spatially structured stock assessment of Indian Ocean yellowfin tuna.

Adam Langley

A spatially structured stock assessment was conducted for yellowfin tuna in the Indian Ocean in 2015. The assessment was conducted in Stock Synthesis and incorporated fishery catches, region specific longline CPUE indices, fishery length compositions and tag release/recovery data. The spatial structure of the model comprised four regions that were defined based on the spatial distribution of key fisheries, spatial differences in CPUE trends from the longline fishery, and the spatial domain of tag releases and recoveries. The model was parameterised to include variation in the regional distribution of quarterly recruitments and age-specific movement amongst regions. Environmental covariates (SST and current) were incorporated in the parameterisation of movement to account for seasonal and inter-annual variation in the regional CPUE indices.

An example of multi-area modeling using CASAL

Sophie Mormede, Alistair Dunn

CASAL is a bayesian age- or length-structured population model software used in the majority of stock assessments in New Zealand. It has some spatial capability as it enables the modelling of populations in a small number of stocks and / or areas, with explicit movement between those areas. The small number of areas is limited by data availability and the estimation of the increasing number of parameters that movement between cells brings. We highlight some of the capabilities of CASAL in that domain, describe a current test case, and introduce Casal2 and improved spatial features compared with CASAL.

Toothfish in the Amundsen Sea region used to be assessed using a single-area model in CASAL. However, patterns in the fits to the mark-recapture data led to the development of two-area models with between the two locations migration estimated. Although model results are unsatisfactory in this instance, the multi-area models developed were useful to test stock hypotheses and inform future research needs.

Spatial survey-based assessment model for the Grand Banks stock of American plaice in Newfoundland and Labrador

Rajeev Kumar and Noel Cadigan

An age-structured survey-based spatial assessment model (SURBA) is developed to estimate the status of the Grand Banks stock of American plaice in Newfoundland and Labrador (NAFO Divisions 3LNO), which is currently under a fishing moratorium since 1995. The state-space cohort model is fitted to the abundance indices for each of the three divisions obtained from Canadian Research Vessel (RV) surveys conducted every year in the spring and fall, and produces division-level estimates of total mortality rates (Z) and stock size relative to survey catchability. The spatial information for the surveys is much more reliable than the historic commercial catch and more recent by-catch, and the spatial SURBA is a first step towards developing a spatial state-space integrated assessment model for this stock.

Historically, the Canadian RV surveys used different gear (i.e. Engel otter trawl) with much different catchabilities than the current gear (i.e. Campelen shrimp trawl). Catchabilities for the Campelen survey are modelled as a logistic function of fish length while the catchabilities for the Engel survey are computed relative to the Campelen using conversion factors derived from comparative fishing experiments. Formulation of the model this way facilitates estimation of gear-wise catchabilities depending on how size changes with age, spatial location, and time. The Z is separated into fishing mortality (F) rates and natural mortality (M) rates. The F for the three management divisions are separated into age-effects and year-effects which are modelled using random walk approaches. The M is assumed to follow Lorenzen's equation of size-based decline and changes over space and time following changes in growth. A combination of process error (shared and separate in the three divisions) are applied in the cohort model, and temporal and spatial correlation is included in recruitment and mortality rates.

Advantages of this interim assessment model include using additional survey data for the assessment compared to the accepted NAFO space-aggregated model, and producing stock status estimates for each Division which are substantially different from each other indicating spatial differences in productivity processes which seem important to consider for sustainable management of the future 3LNO American plaice fishery. Future model developments will include a finer resolution spatial model and incorporating information on uncertain (e.g. location, amount, and size composition) commercial fishery removals.

Accounting for spatial structure in length-and-age-based stock assessment models: An example from South Australia

Jonathan Smart, John Feenstra and Richard McGarvey

South Australia provides one of a few examples where length-and-age-structured models are routinely used in fisheries stock assessments. Here, the slice partition approach is applied to the three primary species of the Marine Scalefish Fishery (a multi-species and multi-gear fishery) to dynamically account for partial recruitment as a portion of each cohort of a species reaches legal minimum length. One of these species (King George Whiting, Sillaginodes punctatus) has a particularly complex life history which, combined with seasonally and geographically varying rates of fishing mortality (F), requires a spatially structured stock assessment model. This is achieved by allowing proportions of the population within cohort length slices to be transferred between specific spatial cells during migration months. King George whiting are spatially disaggregated with 2 and 3-year-old fish residing in northern Gulf St Vincent and Spencer Gulfs while older fish reside in the southern areas of each gulf. Fishing pressure is heaviest in the northern gulfs during winter months and then decreases in summer, at which time this species migrates to the southern parts of each gulf. Consequently, these fish undergo a 'gauntlet effect' where F is highest for the younger age classes. The slice partition approach improves this aspect of the model by accounting for the fact that while faster growing members of a young cohort will undergo greater fishing mortality – the whole cohort is also migrating to regions with lower fishing pressure as migration is age-dependent. This process effectively tracks the level of F encountered by each age and slice by transferring fish in numbers to another region. Without this movement sub model, the F on each cohort within each cell would be inaccurate with overestimated or underestimated F in regions undergoing emigration or immigration, respectively.

Exploratory spatially-structured models for bigeye tuna in the eastern Pacific Ocean

Juan L. Valero, Mark. N. Maunder, Haikun Xu, Carolina Minte-Vera, Cleridy Lennert-Cody and Alexandre Aires-da-Silva

The current stock assessment of bigeye tuna (BET) in the eastern Pacific Ocean (EPO) is structured as a single area, using a fleets-as-areas approach. The underlying assumption of this approach is that BET is randomly mixed within the EPO, with no localized spatial dynamics. However, tagging studies indicate restricted movements and regional fidelity of bigeye in some areas of the EPO, in particular in the equatorial area from around the Galapagos Islands to 120°W. Such restricted movements, combined with the spatial heterogeneity of the fishing effort and the catch, suggest that localized depletion patterns of bigeye sub-stocks may exist in the EPO. A recurrent feature of the assessments of bigeye in the EPO since 2003 is an increase in estimated recruitment, starting in the mid-1990s, resulting in an apparent two-regime pattern of recruitment, with estimates after the mid-1990s about double those of the prior period. Although several hypotheses have been proposed regarding the potential cause of this pattern, recent analyses support a "spatial mismatch" hypothesis, which postulates that the pattern results from spatial misspecification in the stock assessment model, given spatial discrepancies between the dramatic increase in purse seine-catch and the longline catch per unit of effort used as the main index of relative abundance in the BET assessment. In this presentation we discuss work to date on alternative modelling approaches to investigate the impact of both alternative spatial configurations and spatial models on BET assessment results, including age-structured production models and integrated models with and without movement. Results are relevant not only for BET assessments but also for ongoing management strategy evaluation work.

Management implications

Setting boundaries: the intersection of management actions and spatial population structure

Aaron M. Berger and Daniel R. Goethel

Spatial structure is a defining feature guiding the population dynamics and sustainable harvest levels of marine resources. Individual biological responses to spatial heterogeneity in oceanographic conditions, harvest pressure and regulatory measures create complex, non-stationary spatiotemporal demographic patterns that can influence management success (e.g., achieving a desired harvest level or ecosystem service). Spatial management procedures inherently include an explicit definition and treatment of boundaries, which define the population unit of the resource that regulations act upon. Yet, management boundaries tend to be static and determined by politically negotiated or historical management units, which creates a potential disconnect with existing population structure. Ultimately, spatial management procedures need to consider the population components (e.g., spawning contingents or harvest stock) of societal interest that require management action given fishery objectives and associated risk profiles. The risks of ignoring spatial population structure, or incorrectly identifying it, can be high when it comes to providing management advice. We discuss the complexities associated with spatial fisheries management drawing on contemporary research exploring the impact of spatial processes on management effectiveness and how management advice can benefit from improved spatial data and analyses. We then use a spatial simulation-estimation framework to evaluate risks associated with misalignment among management and ecological boundaries when assessing a resource. Continued investment in fine-scale, spatially-referenced data collection methods (e.g., electronic/satellite monitoring or tagging studies) will help further the development of flexible fisheries management procedures that are more robust to spatial fisheries dynamics and ecosystem-level interactions influenced by dynamic environmental conditions.