

Information Paper 8

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**Project update:
Quantifying range contraction in Pacific pelagics**

Oceanic Fisheries Programme, SPC





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1 Introduction

The geographic range size is an important aspect of the ecology of a fish, yet it is seldom accounted for in fisheries management. Many fisheries collapse have been accompanied by an important range contraction of the target species. While the three key tropical tuna stocks: bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), and yellowfin tunas (*T. albacares*) are estimated to be above the levels required to support the maximum sustainable yield, industrial fishing (primarily



School of yellowfin tuna, image ©NOAA.

and periods of unfavourable environmental conditions have reduced the biomass of these tuna stocks relative to 1980 levels from 8% (skipjack tuna) to 65% (yellowfin tuna) (see Figure 1).

Well-studied hypotheses in ecology suggest that range size should decline concurrently with biomass for most species. If stock extent changes with biomass, it could be that certain regions would be overtly affected by biomass depletion even though the overall stock is considered healthy. Changes in range size over time could also bias estimates of stock levels.

The question of range contraction in Pacific pelagics has important management applications but is fundamentally of an ecological nature. Our aim in this project is first to take a step back from tuna fisheries and review the current state of knowledge of the drivers behind species distributions, as well as assess existing methodologies. We review key findings here, as well as briefly discuss preliminary results and possible directions for the analysis of tuna catch-and-effort data under the aim of quantifying range shifts.

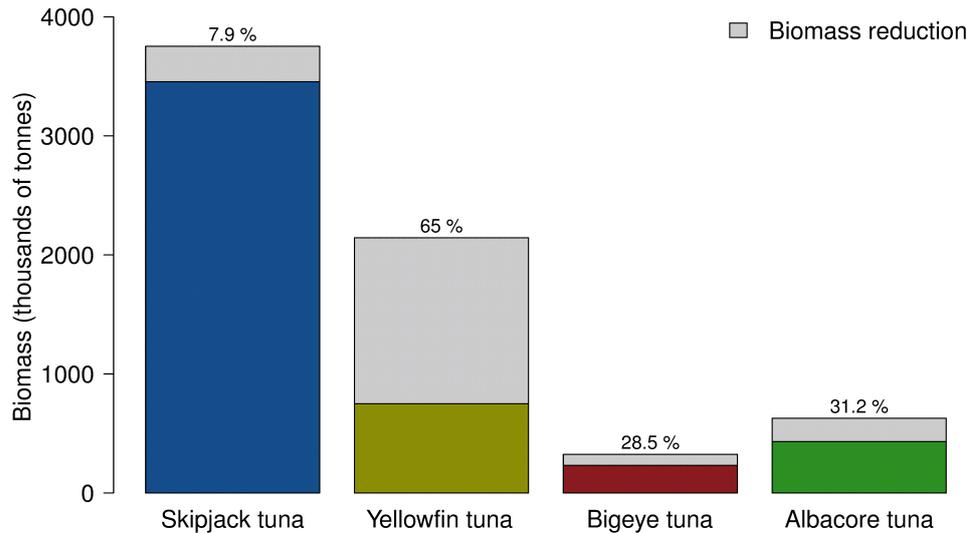


Figure 1: Biomass remaining for the main tropical tuna stocks compared to 1980 levels

2 Range contraction in marine organisms

A species' range has contracted if it is absent in locales where it was formerly present. Accordingly, detecting range contractions relies on time-series of spatial abundance for the species of interest. Such datasets can be assembled from various sources, including natural history records, scientific surveys, fisheries records and anecdotal observations. A key challenge here is to distinguishing between real absences and undetections – *undetections* are instances where the species was present but not documented as such. This can occur if: (1) the species was not targeted in the survey such that its presence was not recorded; (2) the species was targeted in a survey but remained unseen by the observer.

For terrestrial species, extensive historical records of anecdotal observations exist which researchers can rely on to estimate past ranges. Marine pelagic and benthic species are much harder to observe due to the nature of the environment (humans are terrestrial species). Direct observation has only been possible in the last 50 years through the advent of scuba diving, which itself comes with sampling limitations that terrestrial observers are not subjected to. As a result, historical records of marine species mostly come from undirect occurrence data through fishing records, or records of species that can be observed from the surface (e.g. whales, dolphins), use terrestrial environments (sea turtles, seals) or are anadromous (salmons, sturgeons).

There are few documented marine range contractions, but marine species in this regard have received little research attention compared to their terrestrial counterparts. Examples of established range contractions come from marine mammals and sea turtles. Datasets for these species are of higher quality as they are easy to observe and there was

a high (commercial) incentive for non-scientific observers to map their occurrence. Their populations were severely depleted due to commercial hunting and this resulted in range contraction for most.

Most examples of modern range contractions for marine fish come from demersal species directly or indirectly targeted by fisheries in the Atlantic: Atlantic cod, Atlantic wolffish, thorny skate, etc. In addition, a recent study showed that the range of pelagic predators in the Pacific might be declining, however since it was solely based on catch-and-effort data the measured range decline might be confounded with changing patterns in fishing effort allocation.

The range contraction in the Northwest Atlantic cod has been the focus of many studies. The Atlantic cod fishery used to be one of the world's most lucrative and employed about 30,000 people, but the stock collapsed about 20 years ago. Biomass levels have yet to recover despite a fishing moratorium being in place. Some authors attribute the collapse of the Atlantic cod to a failure to account for range contraction in the use of commercial CPUE as an index of abundance. Several hypotheses are posited to explain the range shift: (1) colder temperatures; (2) changes in the distribution of prey-species; (3) depletions of local populations through overfishing. Incorporating the mechanisms at work in the management strategy for this species might have prevented the stock collapse.

Lastly, a recent extensive review of range shifts (with a focus on climate change and exotics) found 129 marine species with a shifted range. Of these, 36 were finfish, with 30 coming from the North Sea. Shifting species tended to have smaller body sizes, faster maturation and smaller size at maturity. While the focus was mostly on climate change, it is interesting to note that species that are resilient to fishing often match this life-history profile.

3 Theory of geographic range as applied to marine species

The geographic range of species integrates multiple facets of its biology and has gathered considerable research attention across a range of subdisciplines: behaviour, conservation science, ecology, evolution, genetics, paleobiology, etc. A diversity of factors affect the geographic range and these factors often interact in complex ways.

A useful framework to make sense of the complex interactions between the drivers of a species distribution is to focus on their effects on basic demographic rates:

$$N = b - d + i - e \tag{1}$$

where N is abundance at a given site, and b , d , i and e represent number of births, deaths, immigrations and emigrations, respectively.

Drivers of distribution change can be understood in terms of the demographic rate they affect. Figure 2 summarizes important determinants of the geographic range of species. For simplicity, the species niche is represented graphically as a function of two environment variables, with the dashed line showing the space that the species could potentially occupy and the solid line showing the space the species occupies in reality. *Dispersal* drives the dynamics of the range by allowing individuals to potentially colonize new sites (i.e. it is the process that results in immigration or emigration from sites).

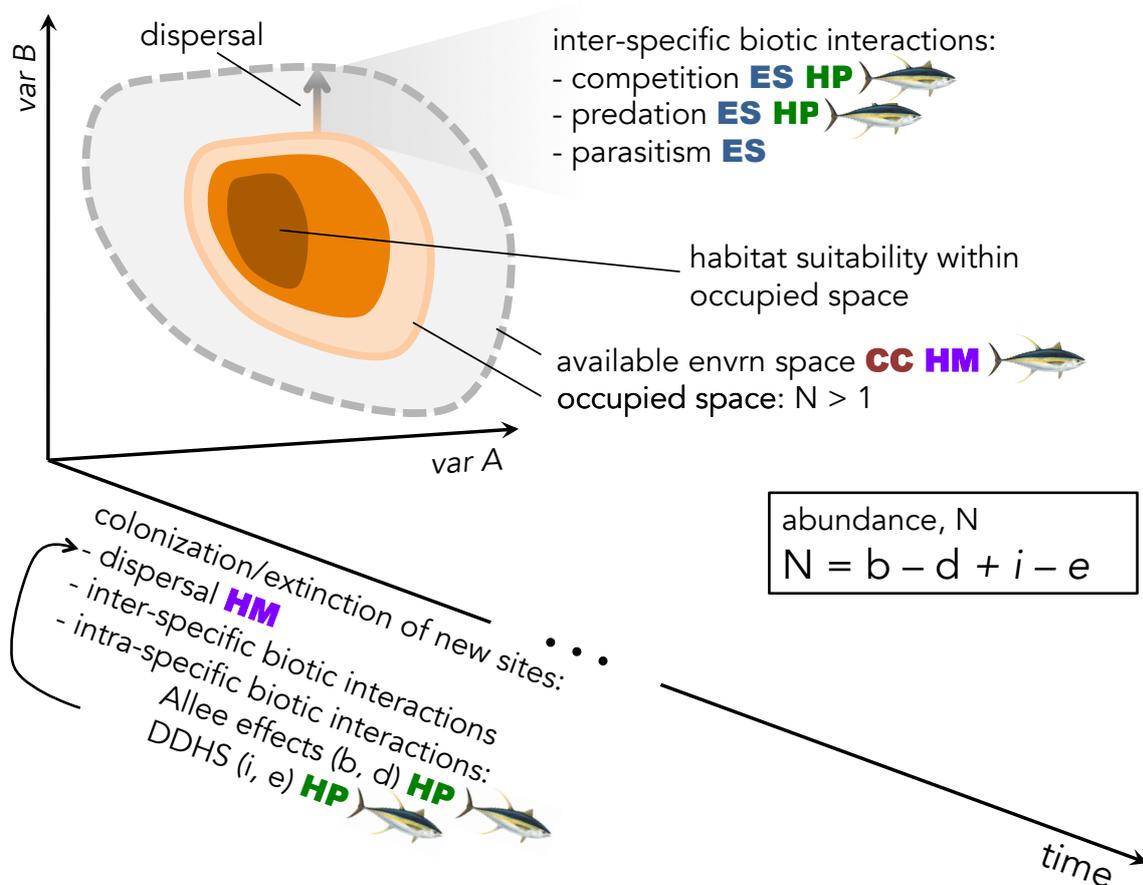


Figure 2: A simplified diagram of the main determinants of the geographic range. The species niche is mapped onto an environmental space defined by two variables. Intrinsic factors that impact a species' abundance N at a site are highlighted, along with the specific demographic rate they affect (birth b , death d , immigration i , emigration e). Main anthropogenic stressors are added beside the factors they impact and labeled as climate change **CC**, habitat modification **HM**, exotic species **ES**, harvesting pressure **HP**.

At *equilibrium*, species are prevented from occupying suitable sites because of *biotic interactions* like competition, predation and potentially parasitism which affect growth rates and the balance between b and d . If not at equilibrium, propagules of the species might not have reached all suitable sites yet. Once propagules reach a new site they might be facing *Allee effects* since their density will be low. These might either prevent them from becoming established until the number of individuals is high enough (higher d), or boost their growth rate once a certain density is reached (higher b). Dispersal rates could be linked to density and increase with local abundance, potentially leading to *density-dependent habitat selection* and/or *abundance-occupancy relationships*.

Integrating anthropogenic stressors: Different human stressors should result in different patterns of range dynamics. Habitat change, for instance, implies different trajectories of decline and potential recovery for species. Since the habitat is modified, the geographic location of the niche is changed such that range contraction occurs automatically, whereas demographic factors such as over-harvesting do not necessarily imply range contraction (though they may do so through abundance-occupancy relationships).

The four main anthropogenic threats can be integrated in terms of the distribution process they directly affect. Both climate change (CC) and habitat modification (HM) change the spatial distribution of abiotic variables in the environment and affect the birth and death rates at a given locale by modifying the habitat suitability. Habitat modification could also affect dispersal rates if species cannot move successfully in a fragmented habitat. Exotic species (ES) introduce new competitors, predators or parasites in the environment of native species, so can change the amount of habitat they can successfully occupy within the environment that is suitable for them. Lastly, harvesting pressure (HP) directly decreases abundance so that it can trigger, in addition to increasing death rates, other processes linked to density like Allee effects and density-dependent habitat selection. It can also affect biotic interactions indirectly by depleting a species' predators or competitors.

Application to marine highly-mobile pelagic fish: This framework can be applied in light of the life-history and ecology of marine, highly-mobile, pelagic species (MHP, fish symbol on Figure 2). Habitat alteration – in terms of the seafloor – is unlikely to be an issue in marine pelagic environments so its effects can be ignored. Exotic species are also unlikely to be an issue, as competitors and predators of MHP are already wide-ranging. Climate change and harvesting pressure are the two main threats remaining that could result in a distribution shift. Climate change would affect the distribution of habitats available for MHP to colonize, and the location of suitable habitats within

the range. Harvesting pressure increases death rates which could (1) cause local depletion if sub-populations use specific migration routes and are being overfished; (2) trigger distribution-abundance relationships which could result in contraction if individuals select habitat based on suitability. Some key questions to address would be the processes behind the colonization of new sites, the importance of breeding site/migration route fidelity, the existence of density/home-range dynamics, mechanisms behind individual decisions about habitat use and the existence of fine population structure.

4 Range contraction in yellowfin tuna: preliminary findings

We use the yellowfin tuna as a sample species to test potential methods to measure range contraction in MHP. The first step is to construct a dataset of species occurrence that covers the historical distribution of the species over the time-scale where the contraction is thought to occur.

Catch-and-effort data is available for a large area in the Pacific and covers the onset of industrial longline fishing. There are however many holes left in the data (e.g. see Figure 3 for the Japanese fleet). In order to fill these gaps, we can impute a cell's missing information based on data for that cell in other years or from data in neighbouring cells. We used a semi-parametric generalized additive model (GAM) approach to fit a spline surface to the existing CPUE data (see Figure 3).

This approach allows to predict catch rates for the Pacific since the 1950s and can be used to map decline rates in CPUE in space (Figure 4). However the model at this stage still needs to account for (1) oceanography, as oceanographic conditions could further inform predictions for missing cells; (2) biases in the catch and effort data due to changes in fleet and targeting. A common approach to handle biases in CPUE data is to extract the years effects from a GLM that includes a high number of explanatory variables. However this approach is often criticized for overfitting the data and resulting in biased predictions.

We aim to develop next a hybrid methodology that incorporates a statistical approach from conservation science – occupancy modelling – to convert the catch records dataset into a set of presence/absence data. Occupancy modelling is a statistical framework that allows to distinguish real absences from both the lack of detections and changes in the rate of species detection (here, detection = species caught). While information about relative abundance would be lost, doing so would enable us to ignore the biases inherent

Predicted CPUE surfaces for YFT in quarter 3 from:
 $\log(\text{yft_cpue} + 0.05) \sim s(\text{lond}, \text{by} = \text{flatd}) + \text{flag} + s(\text{latd}, \text{by} = \text{fqtr}) + s(\text{yy5i}, \text{by} = \text{flatd})$

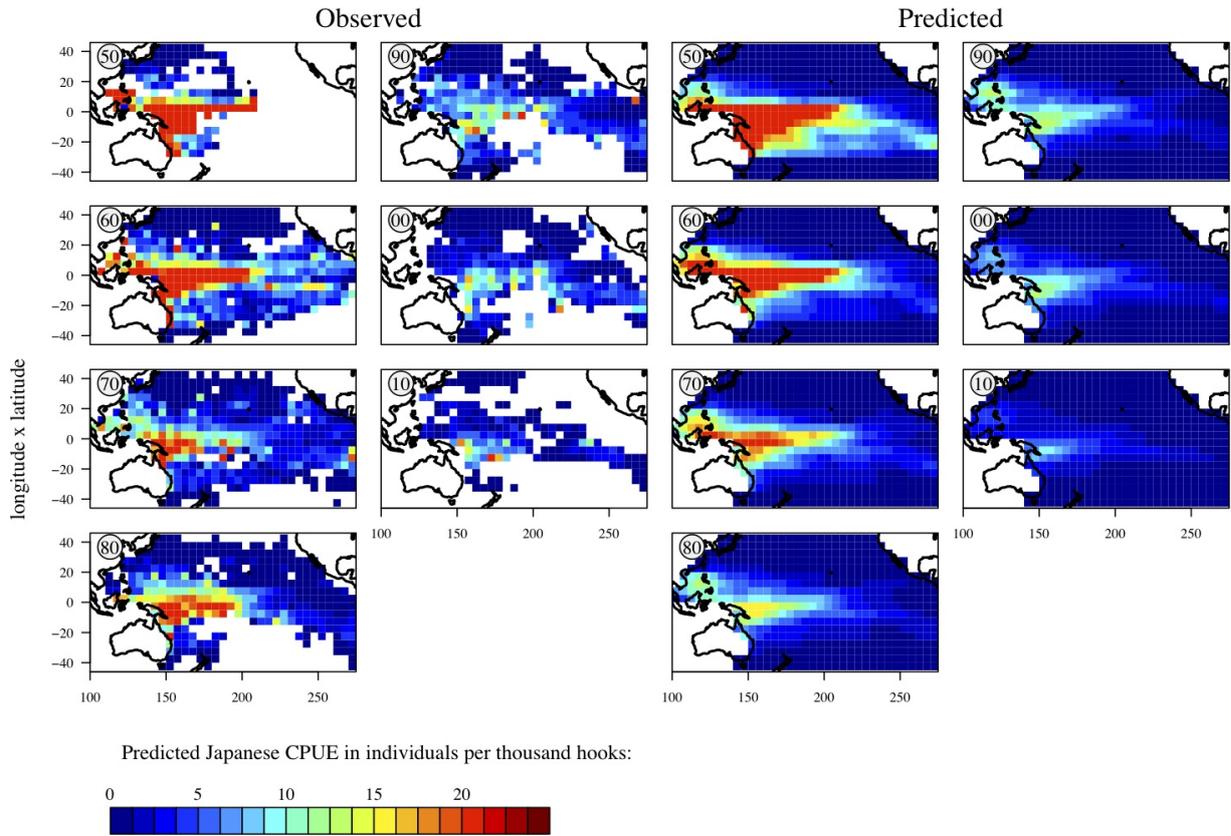


Figure 3: Observed vs predicted data from a semi-parametric GAM for the CPUE data from the Japanese fleet. According to this model there has been a contraction of high abundance areas towards the Equator. Note that this model starts goes from 1950s onwards and includes the sharp drop in CPUE indices that occurred at the start of the fishery.

to CPUE datasets. Once the boundaries of the range have been defined, knowledge about habitat suitability and fisheries catches could be combined to generate relative abundance trends within the range boundaries under different hypotheses of abundance-occupancy relationships.

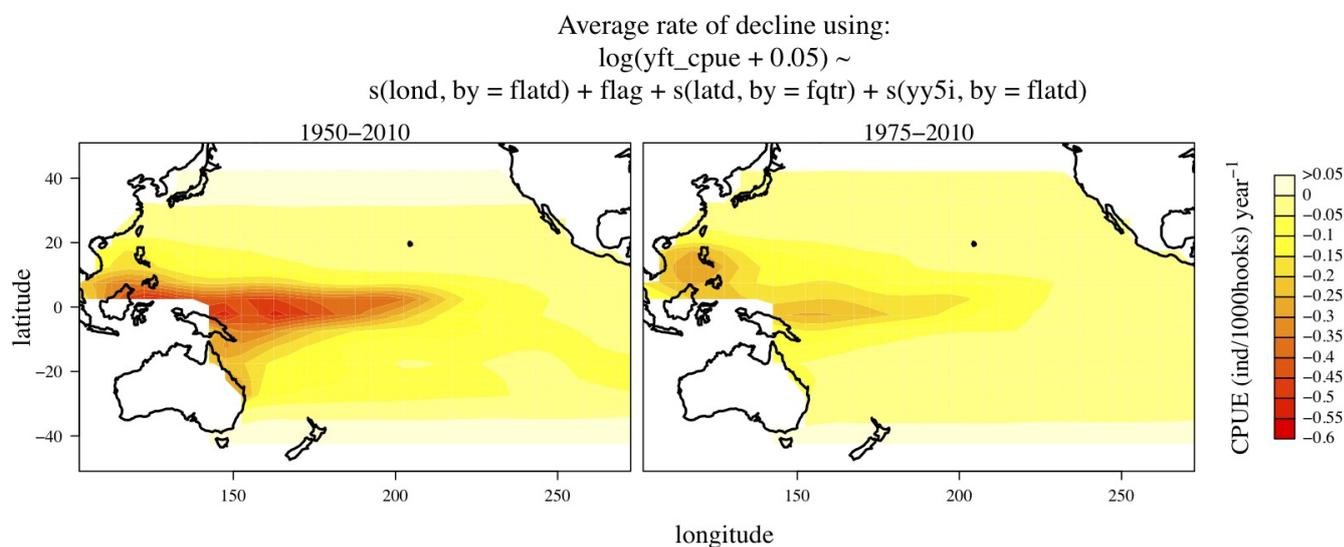


Figure 4: Slope of CPUE decline over time (from a linear regression) based on predictions from the model run on all years (left), and from 1975 onwards (right). The decline is predicted to be stronger in the tropics, but is less pronounced when only the last 35 years are used to compute the rate of decline.