Title: Influence of the North Pacific Current on the spatial distribution and availability of north Pacific albacore tuna in the Northeast Pacific Ocean

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Background: This project will improve our understanding of how changes in the position of the North Pacific Current (NPC) and bifurcation latitude influences the spatial distribution of north Pacific albacore tuna (*Thunnus alalunga*) in the Northeast Pacific (NEP), with the aim of developing an environmental time series that indicates the availability of the stock to NEP fisheries. Stock assessments of highly migratory species (HMS), like albacore, rely on standardized catch-per-unit-effort (CPUE) indices from different regional and seasonal fisheries to indicate trends in abundance due to the inability to conduct scientific surveys that cover the entire ocean basin. However, due to their high mobility, the availability of these fish to regional fisheries is highly variable and is related to environmental conditions. This variable availability results in abundance indices being less reliable as indicators of overall abundance and leads to greater uncertainty in assessment results. For example, in the 2011 assessment of north Pacific albacore tuna, the assessment used an index derived from the surface fisheries in the NEP (ISC 2011). However, these fisheries are currently highly coastal and the albacore distribution in NEP coastal waters straddle the international border between the US and Canada, and the effort of the US fleet in Canadian waters (and vice versa) is managed by the US-Canada albacore treaty (Teo et al 2010). Therefore, as the albacore distribution shifts north-south or offshore-onshore, the availability of albacore to these coastal fisheries likely changes. Although the availability of albacore to NEP fisheries have been variable, the assessment has not explicitly accounted for changes in availability due to a lack of understanding of how albacore spatial distribution and availability in the NEP varies through environmental variability. Instead, the assessment assumed a larger coefficient of variation (CV) for this index due to this uncertainty.

Potential ways to reduce the uncertainty in HMS abundance indices include developing an environmental index that explains the changes in availability. The proposed index can be integrated into a statistical catch-at-age model to test hypothesized relationships between the environment and availability. By testing these hypotheses within an assessment framework, we can better estimate and explain the uncertainty in these relationships and how these environmental time series affect overall assessment results.

Albacore tuna are widely distributed throughout the temperate and subtropical waters of the world. In the Pacific Ocean, albacore is thought to consist of a north Pacific stock and a south Pacific stock. North Pacific albacore spawn primarily in the tropical and subtropical waters of western and central Pacific during the second quarter (Ueyanagi 1969). After hatching, young-of-year albacore grow rapidly, reaching ~57 cm at age-1+ (Wells et al 2011), when they recruit to surface fisheries in the NEP. North Pacific albacore are known to exhibit extensive migrations between the NEP and the western and central Pacific, as well as between temperate and subtropical waters (Childers et al 2011, Ichinokawa et al. 2008). Of importance to US fisheries, juvenile albacore (ages 1-4) migrate seasonally from the western and central Pacific to the North American coast along the North Pacific Transition Zone, typically arriving on the west coast in summer (Laurs & Lynn 1991, Polovina 2001) (Fig. 1). After spending several months along the west coast, the albacore typically leave coastal waters for the western and central Pacific. There are thought to be two main groups of albacore along the west coast, with a northern group ranging from Vancouver Island to Cape Mendocino, and a southern group ranging from Central California to Baja California. During their stay along the west coast, albacore feed primarily on anchovy (*E. mordax*) and saury (*C. saira*) but have also been found feeding on cephalopods and other fish species (Glaser 2005).

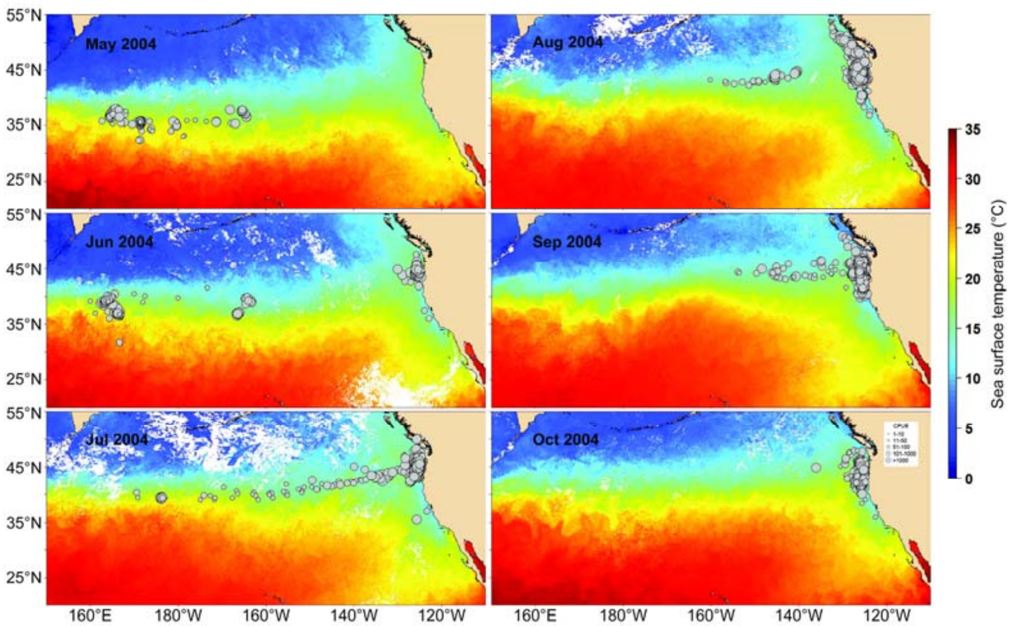

Fig 1. CPUE (grey circles) of north Pacific albacore by US surface fisheries and sea surface temperature from May to October 2004.

The north Pacific albacore surface fishery is the most important HMS fishery on the west coast in terms of number of participating vessels (651 commercial boats in 2010) and ex-vessel value (~$30 million in 2010) (PFMC 2011). The US commercial albacore fishery consists primarily of troll and pole-and-line vessels and has in recent years concentrated on the northern group of albacore, whose distribution straddles the coastal waters of the US and Canada. The original US-Canada albacore treaty in 1981 allowed for unlimited cross-national access for both countries' fleets but was amended in 2002 to limit the number of Canadian vessels in US waters and vice versa. These treaty limits are renegotiated every few years. It is therefore important that environmental influences on albacore distribution in the NEP are better understood so that an equitable allotment of cross-national access may be negotiated.

In recent years, we have begun to have a better understanding of the influence of the NPC on the NEP ecosystem. The position of the NPC and bifurcation latitude have been shown to have substantial variability, which in turn has downstream effects on the NEP ecosystem (Sydeman et al. 2011) (Fig. 2). Since north Pacific albacore follow the NPTZ to reach the west coast (Fig. 1), we hypothesize that the position of the NPC and bifurcation latitude will influence albacore distribution in the NEP, with a more southern bifurcation latitude resulting in a more southern distribution. In addition, shifts in NPC position may also influence the longitudinal distribution of albacore because a more southern bifurcation latitude results in a weaker California Current and decreased productivity in the California Current ecosystem and vice versa

(Sydeman et al. 2011). For example, decreased productivity in the California Current system may result in a shorter stay in the NEP for this highly mobile stock. Understanding how shifts in the NPC affect NEP ecosystems is important because one of the clearest results from GCMs are poleward shifts in westerly winds, which would lead to a more northerly NPC (Sydeman et al 2011). Although this project will concentrate on the effects of the position of the NPC, other local (e.g., SST, SSHA, MLD) and basin scale indicators (e.g., PDO, NPGO, SOI), and biological (e.g., anchovy abundance) variables also likely influence the distribution of albacore and are included in our analysis for completeness.

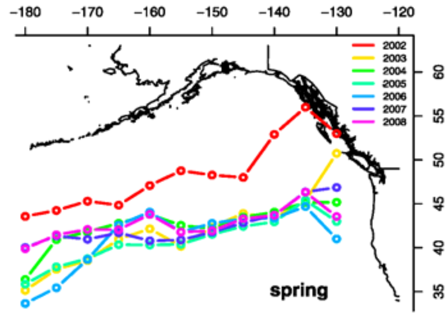

Fig 2. Latitude of the dividing streamline between waters flowing north and south for every 5° of longitude for the NPC across the North Pacific. From Sydeman et al. (2011)

Approach: Our working hypothesis is that shifts in the NPC are related to changes in albacore distribution, which affects the availability of albacore to US and Canada vessels in the NEP. Our aim is to develop an environmental time series that indicates the availability of north Pacific albacore to US and Canada fisheries, which is then integrated into the assessment model.

Fisheries Data: We will first assemble a database containing daily, location-specific, catch and effort data from both US and Canada albacore vessels in the NEP, extending from 1961 till the present. For this project, collaborating Canadian scientists from DFO have agreed to contribute logbook data from Canadian vessels, which will be integrated with logbook data from US vessels. Any identifying information will be removed prior to incorporation into the database to allay privacy concerns. Over the past two decades, albacore ranging from Central California to Baja California have increasingly been targeted by recreational rather than commercial vessels. Therefore, logbooks from the Commercial Passenger Fishing Vessel (CPFV) fleet will be integrated into the database to help identify the distribution of albacore in this region. Since 2001, the SWFSC have also deployed electronic tags on albacore tuna, which will help us identify the migrations of individual fish in the NEP (Childers et al. 2011) (Fig. 3).

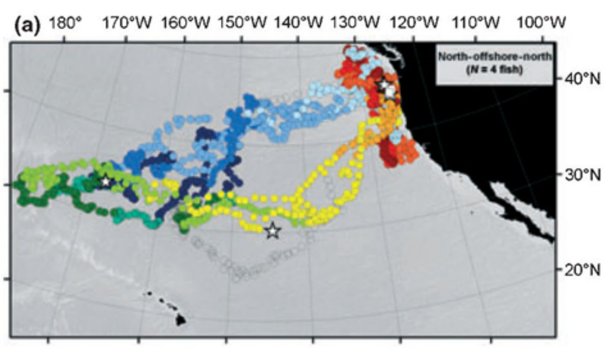

Fig 3. Tracks of four individual albacore tagged in coastal NEP waters (white square). Colors indicate month and white stars indicate recapture location. From Childers et al. 2011.

From the above data, the albacore CPUE (fish per boat day) will first be calculated for every 2 weeks and 1° square, which will provide biweekly CPUE fields in the NEP. We intend to identify the main path of albacore from logbook and electronic tag data as they move towards the west coast (Figs. 1 & 3) and the timing and location at which albacore first enters coastal waters (east of 130 ºW). Subsequently, we will determine the center of mass of the albacore distribution in coastal waters and the range of the distribution. The analysis would be limited to the period between May and October because that is the main fishing season.

Environmental Data: We will develop and compare time series of NPC position and bifurcation latitude of different durations based on data from the Argo array (2002-present), satellite altimetry (1992-present), and SODA model output (1958-present). Based on the methods in Sydeman et al (2011), the latitudinal position of the NPC will be determined at 180 to 130 ºW in 5º intervals for spring and summer, based on differences in dynamic heights. The fisheries data extends from 1961 but the Argo array and satellite altimetry only provide data from 2002 and 1992 respectively. Therefore, we will compare the NPC latitudes from these different data sources in order to corroborate any differences in these data sources.

Although we will concentrate on the effects of NPC position variability, we will also examine how local and basin scale ocean conditions affect albacore distribution. The analysis will include local conditions like weekly fields of remotely-sensed sea surface temperature (SST), SST fronts, sea surface height anomalies (SSHA), chlorophyll concentration and wind stress, which have all been previously associated with albacore distribution (e.g., Laurs & Lynn 1991, Polovina 2001, Zainuddin et al 2006, Zainuddin et al 2008, Sagarminaga and Arrizabalaga 2010). The basin scale indicators examined will include the Pacific Decadal Oscillation, North Pacific Gyre Oscillation, El Nino Southern Oscillation, and NEP coastal upwelling indices. In addition, we will include information on the distribution of anchovy and saury, which are their primary prey in NEP coastal waters, wherever available.

Statistical Analysis and Modeling: Several preliminary analyses will need to be performed prior to model development. An EOF analysis will first be conducted on the albacore CPUE fields and the NPC latitudes to extract the primary modes of variability of albacore CPUE and NPC position. This will also help us identify the main areas where CPUEs are relatively coherent and the relationship between these areas. Since many of the local environmental variables are closely related to each other, we intend to use EOFs of local environmental variables rather than geophysical values in our later analyses. Secondly, the migration paths and distribution metrics of the albacore will be compared and corroborated with corresponding CPUE and electronic tag data.

After the preliminary analyses are completed, we will relate the variability in albacore distribution to changes in ocean conditions using a series of statistical models and model selection methods. Although the exact analytical method will depend on preliminary analysis and the technical skills of the postdoctoral researcher, we intend to use a series of Generalized Additive Models (GAMs) (Wood 2006) or Boosted Regression Trees (BRTs) (Elith et al 2008), with the albacore distribution metrics and local albacore CPUEs as response variables. The EOF1 of NPC position, as well as other environmental and biological variables listed above will be used as explanatory variables. Cross-validation and model selection will be performed. The primary aim of these models is to identify variables that affect the distribution and availability of albacore in the NEP, as well as produce models that explain changes in the albacore distribution.

After identifying the most important variables affecting albacore distribution and availability, these time series will be integrated into the most recent albacore stock assessment model. The most recent albacore assessment uses Stock Synthesis as the modeling framework, which includes an option for relating estimated parameters to an environmental index as well as annual deviations. Environment-linked changes in albacore availability to the NEP fisheries can be modeled in two ways: 1) assume environment-linked, time-varying catchability of the NEP index, or 2) assume environment-linked, time-varying movement between the western and eastern Pacific. Currently, we have not decided on which modeling approach is preferred and would have to experiment with both approaches. Regardless of modeling approach, if the environmental time series has explanatory power for the availability of albacore to the NEP surface fisheries, it will result in a better fit of the data to the model. We will compare the results of models incorporating environmental time series with 1000 random simulations to determine the probability that any apparent improvements are due to a spurious relationship.

Benefits: The benefits of this project are:

1) most importantly, this project will improve our understanding of how changes in the position of the NPC and bifurcation latitude as well as other local and basin scale environmental conditions influence the spatial distribution and availability of albacore tuna in the NEP;

2) which will in turn allow us to develop an environmental time series that indicates the albacore availability to NEP fisheries and integrate the proposed environmental time series into the north Pacific albacore stock assessment model (described in the section on *Statistical Analysis and Modeling*). Overall, we expect an improvement of model fit to the albacore abundance index in the NEP and a reduction in the uncertainty of the stock assessment results. Since some of the PIs are the lead analysts for the assessment and members of the management team, the results of the study will be presented to the assessment and management teams (both domestic and international) for this stock;

3) improving our understanding of the environmental influences on albacore spatial distribution in the NEP will also be highly valuable for fisheries managers negotiating the US-Canada albacore treaty. We hypothesize that variations in the proportion of albacore in US versus Canadian waters are linked to changes in the NPC position and possibly other environmental changes. Therefore, the results from this study will help managers understand this variability and help negotiate an equitable allotment of cross-national access.

4) the modeling techniques for this project could also be translated to other assessments of HMS stocks. For example, the current Pacific bluefin tuna assessment has several issues related to the variable availability of tuna in the eastern Pacific. Therefore, incorporating environment-linked time-varying availability into the Pacific bluefin tuna assessment model may also be beneficial.

Deliverables: An environmental time series that indicates the availability of north Pacific albacore to US and Canada fisheries in the NEP will be developed, and a postdoctoral researcher will be trained in integrating fisheries oceanography with stock assessments. Results will be:

1) presented in technical documents and oral presentations to the Albacore Working Group (ALBWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), which performs the assessment for the north Pacific albacore stock. Suzanne Kohin is the head of the US delegation to the ALBWG and Steven Teo is the lead analyst for the north Pacific albacore assessment. John Holmes is the chair of the ALBWG;

2) presented in oral presentations to the HMS Management Team of the Pacific Fisheries Management Council (PFMC), which manages the main US albacore fisheries. Suzanne Kohin is a member of the HMS Management Team;

3) presented in oral presentations to the US-Canada albacore treaty data working group, which advises the US and Canada delegations on data pertinent to the US-Canada albacore treaty. Steven Teo and John Holmes are the chair and vice-chair of the working group;

4) published in peer-reviewed scientific journals.

References:

Childers, J., S. Snyder, and S. Kohin. 2011. Migration and behavior of juvenile North Pacific albacore (*Thunnus alalunga*). *Fish. Oceanogr.* 20:157-173.

Elith, J., J. R. Leathwick, and T. Hastie. 2008. A working guide to boosted regression trees. *J. Anim. Ecol.* 77:802-813.

Ichinokawa, M., A. L. Coan Jr., and Y. Takeuchi. 2008. Transoceanic migration rates of young Pacific albacore, *Thunnus alalunga*, from conventional tagging data. Can. J. Fish. Aquat. Sci. 65:1681-1691.

ISC Albacore Working Group. 2011. Stock assessment of albacore tuna in the north Pacific Ocean in 2011. Report of the ISC Albacore Working Group Stock Assessment Meeting, 4-11 June 2011, Shimizu, Shizuoka, Japan.

Glaser, S. M. 2005. Foraging ecology of North Pacific albacore in the California Current System. PhD Thesis. University of California, San Diego. 213pp.

Laurs, R. M. and R. J. Lynn. 1991. North Pacific albacore ecology and oceanography. In J. A. Wetherall (ed.) *Biology, Oceanography and Fisheries and the North Pacific Transition Zone and Subarctic Frontal Zone*. NOAA Technical Report. NMFS 105. p69-87.

Pacific Fishery Management Council. 2011. Status of the U.S. West Coast fisheries for highly migratory species through 2010: stock assessment and fishery evaluation. September 2011. 164pp.

Polovina, J. J., E. Howell, D. R. Kobayashi, and M. P. Seki. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. *Prog. Oceanogr.* 49:469-483.

Sagarminaga, Y. and H. Arrizabalaga. 2010. Spatio-temporal distribution of albacore (*Thunnus alalunga*) catches in the northeastern Atlantic: relationship with the thermal environment. *Fish. Oceanogr.* 19:121-134.

Sydeman, W. J., S. A. Thompson, J. C. Field, W. T. Peterson, R. W. Tanasichuk, H. J. Freeland, S. J. Bograd, and R. R. Rykaczewski. 2011. Does positioning of the North Pacific Current affect downstream productivity? *Geophys. Res. Lett.* 38:L12606.

Teo, S. L. H., H. H. Lee, and S. Kohin. 2010. Time series associated with albacore fisheries in the Northeast Pacific Ocean. Working document submitted to the ISC Albacore Working Group Meeting 12-19 October 2010, Southwest Fisheries Science Center, NOAA, La Jolla, California.

Ueyanagi, S. 1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga*. *Bull. Far Seas Fish. Res. Lab* 2:177-256.

Wells, R. J. D., S. Kohin, S. L. H. Teo, O. E. Snodgrass, and K. Uosaki. 2011. Age and growth of North Pacific albacore (*Thunnus alalunga*). Working document submitted to the ISC Albacore Working Group Meeting 30 May-11 June 2011, Shimizu, Shizuoka, Japan.

Wood, S. N. 2006. Generalized Additive Models: an introduction with R. CRC Press, Boca Raton, Florida, USA. 392pp.

Zainuddin, M., H. Kiyofuji, K. Saitoh, and S. Saitoh. 2006. Using multi-sensor satellite remote sensing and catch data to detect hot spots for albacore (*Thunnus alalunga*) in the northwestern North Pacific. *Deep Sea Res. II* 53:419-431.

Zainuddin, M., K. Saitoh, and S. Saitoh. 2008. Albacore (*Thunnus alalunga*) fishing ground in relation to oceanographic conditions in the western North Pacific Ocean using remotely sensed satellite data. *Fish. Oceanogr.* 17:61-73.