Incorporating indicators of environmental suitability and catchability into existing Atlantic bluefin tuna abundance indices from the Gulf of Mexico

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Project Summary
Commercial longline fisheries in the northern Gulf of Mexico (GOM) target yellowfin tuna (Thunnus albacares), bigeye tuna (Thunnus obesus) and swordfish (Xiphias gladius), with Atlantic bluefin tuna (Thunnus thynnus) also taken as bycatch (Beerkircher et al., 2009). Catch rates of bluefin tuna are formulated into an index of abundance (Cass-Calay, 2007), which is one of several inputs to the western Atlantic stock assessment. However, fishing vessels set their gear in configurations to maximize catches of target species, which have different behaviors, gear vulnerabilities and oceanographic preferences to bluefin tuna (Teo and Block, 2010). Fisheries-dependent indices of abundance for bluefin tuna in the GOM may therefore be biased by any interannual variability in fishing strategies, such as hook sizes and types, hook depths, bait types and water masses targeted.

This project aims to investigate the effects of incorporating gear and environmental variables into the existing GOM bluefin tuna index, using multivariate, non-parametric models. Outcomes of this work will include:

1) Spatiotemporal catchability and habitat models for bluefin tuna, and other large pelagic fishes, caught on commercial longline gear in the northern GOM,
2) An assessment of the influence of changes in gear configurations through time (e.g. the adoption of circle hooks) on bluefin tuna catch rates, and index values,
3) New, experimental indices of adult bluefin tuna abundance in the GOM, corrected for prior probability of capture, and zero-inflation,
4) Assessment of the effect of the new index on estimates of spawning stock biomass, and comparison with other indices of abundance from the North Atlantic.

This project will directly address the aim of the FATE program, to “develop and evaluate ecological and oceanographic indices to improve stock assessments”. Bluefin tuna is an intensively managed species, and NOAA-NMFS scientists are heavily involved in related decision making and working groups, through the International Commission for the Conservation of Atlantic Tunas (ICCAT). An assessment of environmental influences on current stock assessment inputs, leading to potentially improved indices, is of significant interest and use to national and international stakeholders, and resource managers.

Background
Atlantic bluefin tuna are highly migratory, and capable of trans-Atlantic crossings (Block et al., 2001). However spawning activity is largely restricted to the Mediterranean Sea in the eastern Atlantic, and the Gulf of Mexico in the west (Scott et al., 1993). During the spring spawning season in the Gulf of
Mexico, bluefin tuna are regularly caught on longline fishing gears: initially as part of a directed fishery in the 1960s and 1970s, and then as bycatch from other fisheries targeting yellowfin and bigeye tuna, and swordfish (Beerkircher et al., 2009). Records from vessel logbooks are used to construct catch rate indices for the western stock, which are then input to stock assessment models (Cass-Calay, 2007).

Due to their physiology, bluefin tuna occupy different oceanographic habitats to other, more tropical tunas. A unique circulatory system allows bluefin tuna to tolerate cold (<5°C) waters, and has facilitated their expansion into feeding areas in the north Atlantic (Lutcavage et al., 2000). Although bluefin tuna migrate long distances to reach the GOM and spawn, they may be adversely affected by warm (>28 to 30°C) waters (Blank et al., 2004), and show behavioral patterns to avoid warm features in the GOM, such as the Loop Current (Teo et al., 2007). In contrast, yellowfin tuna are caught across most of the open GOM, including the Loop Current, warm eddies, and relatively high-chlorophyll nearshore waters (Teo and Block, 2010). Feeding and spawning behaviors are also likely to drive spatiotemporal variability in catch and distribution of different species, although these constraints are less well known.

Bluefin tuna are highly valuable, with prices of individual fish exceeding $100,000 on the Japanese market (Porch, 2005). Historically, this species has been heavily exploited, and is currently considered to be overfished, and undergoing overfishing (Anon, 2010). A steep decline in the western Atlantic stock was recorded in the 1970s, with numbers estimated to have stabilized at low levels since this time (Rooker et al., 2007). Management is complex and often controversial, due to migratory movements of fish across multiple exclusive economic zones, and mixing between the eastern and western stocks at various life stages. Both western and eastern Atlantic bluefin tuna stocks are under rebuilding plans, with the objective of recovering the stocks to BMSY (biomass at maximum sustainable yield) with at least 50% probability by 2018 and 2023, respectively. Determining both stock status and evaluating the effectiveness of the rebuilding plan requires accurate indicators of abundance.

As the only known spawning ground for western bluefin tuna, the GOM is a key area; both for spawning but also for indexing the stock, as bluefin found here are exclusively of western origin. This elevates the importance of the larval and pelagic longline indices because they, unlike most all other indices of bluefin tuna abundance, can be applied with 100% surety to the western stock. While substantial improvements to the larval index have been made in recent years (FATE project 07-03: Richards et al.; Ingram et al., 2010; and Muhling et al., 2010) the pelagic longline index has received very little attention. The proposed project will contribute to this by assessing the influence of the oceanographic environment and fishing gear on catch rates of bluefin tuna in the GOM, and thus existing catch rate indices.

Methods
Fisheries and environmental data
Fisheries catch data will be sourced from logbooks kept by vessels in the United States pelagic longline fleet (1986 to present), and records from the NOAA-NMFS pelagic observer program (1992 to present). In each dataset, the date, time and location is recorded for the start and end of the longline set deployment, and of the start and end of the gear haul. Catches of fish of each species are recorded, and some data on fish lengths and sexes are also available in the observer database only. Additional information on gear configurations and target species will also be included.
The bluefin tuna catch rate indices currently in use have been developed using a delta-lognormal approach (Lo et al., 1992). This method combines separate generalized linear modeling (GLM) analyses of the proportion of positive sets and the catch rates of positive sets to formulate a single, standardized index of abundance (Cass-Calay, 2007). At present, year, month, vessel ID and zone of the GOM are included as covariates in the model. The proposed project will extend these methods to incorporate variability in catch rates due to the oceanographic environment around the set location, and differences in fishing gears used.

Environmental data for inclusion in the predictive distribution models will be extracted from remotely-sensed satellite data, and ocean models, such as HYCOM (the HYbrid Coordinate Ocean Model data assimilative system: Chassignet et al., 2007). A range of sources for satellite products are available, including the MODIS-Aqua, AVHRR Pathfinder and SeaWiFS platforms, for sea surface temperature and chlorophyll, and AVISO altimetry products, for sea surface height, height anomaly and geostrophic currents.

Sea surface temperature, surface height, surface height anomaly, surface chlorophyll, current velocity and eddy kinetic energy will be extracted for the beginning and end of each longline set and haul in the fisheries database. The temporal coverage of both satellite and ocean model datasets is variable, and often shorter than the extent of the fisheries database. A model covering the period from 1993 to present, utilizing sea surface temperature, height, height anomaly, geostrophic current velocities and eddy kinetic energy will be constructed initially, followed by additional model experiments over shorter time-frames, incorporating surface chlorophyll (1998 to present), and variables extracted from ocean models.

While predictions from ocean models may not perfectly resolve in situ conditions, and do not extend as far back in time as satellite products, they have the advantage of superior spatial and temporal coverage as they are not affected by clouds (temperature and chlorophyll sensors), or low temporal resolution (altimetry sensors). As part of the proposed project, variables generated from both satellite data and ocean models will be examined for inclusion in predictive models, and compared in terms of feasibility and accuracy. If practicable, algorithms describing habitat suitability for bluefin tuna, or another species of interest, will be applied to ocean model data, enabling near real-time predictions of catch likelihoods across the northern GOM.

Models of catch rate and abundance
Environmental variables will be combined with other descriptors of potential catchability, including hook type, gear depth, bait type and other gear factors, into a multilayer perceptron neural network predictive model. Artificial neural network models are useful and accurate predictive techniques which make no prior assumptions regarding data distribution, and can model highly non-linear functions. They have been shown to perform as well, or better, than other leading non-parametric methods such as generalized additive models (Segurado and Araujo, 2004), and consist of systems of interconnected nodes, connected by non-linear transfer functions (Gardner and Dorling, 1998). The predictive model will be trained on 80% of the available dataset, with 20% withheld for model validation, to prevent overfitting. This approach will define the influence of both environmental conditions and gear configurations on catch rates and abundances of bluefin tuna. A probability of occurrence can be generated for any given set of conditions, as well as a predicted catch per unit effort (CPUE). Separate models will also be initialized for yellowfin and bigeye tuna, and swordfish, and habitat preference
overlap among species will be quantified. This project will thus extend the initial work of Teo and Block (2010), by incorporating logbook catch rate data, fishing gear factors, additional environmental variables, and by providing a mechanism for direct incorporation of results into an existing stock assessment index.

Construction of alternative indices
The delta-lognormal models currently used for GOM bluefin tuna indices combine a logistic (binomial) model describing the proportion of positive sets, with a lognormal model describing the variability in the non-zero data (Lo et al., 1992). The methods proposed here would test the effects of including a metric of “habitat suitability” in both the logistic and lognormal portions of the model. The effects of replacing either portion of the model with a non-parametric neural network model, instead of a GLM, will also be investigated. In addition, we will test the ability of the zero-inflated delta-lognormal model of Ingram et al. (2010) to better describe the proportion of positive sets for bluefin tuna. As bluefin tuna are taken as bycatch, they occur in much lower numbers than other, target species. This is likely to be a combination of “true” zeros (from rarity and habitat suitability), and “false” zeros (from catchability). The zero-inflated delta-lognormal model attempts to address these issues and may improve model fit.

The effects of incorporating environmental information into existing indices will be tested by comparing the fit of each candidate index within the stock assessment model. Candidate indices can be tested by comparing the objective function values of models using each index within the existing virtual population analysis (Porch 2005). This evaluates which formulation of the GOM pelagic longline index is most consistent with all of the other available information (12 CPUE indices, catch at age and landings). The GOM pelagic longline index currently shows a very poor fit in the VPA model (Figure 1).

Leveraging previous work
A previously funded FATE project (07-03: Richards et al.) applied measures of environmental variability to another index of bluefin tuna spawning stock biomass: the GOM larval index. Significant variability in the larval index was assigned to environmental and gear factors, and inclusion of habitat suitability measures improved the behavior of the index. A larval habitat model was developed (Muhling et al., 2010), which allowed the prediction of spawning suitability based on environment. This work confirmed that the larval index decreased sharply in the late 1970s, and has remained relatively stable since this time. In contrast, the GOM pelagic longline index shows higher values in the late 1980s, before declining through 1995, and increasing slightly through 2010 (Figure 1). By combining results from both life stages, this project will examine potential reasons for this discrepancy. Interannual variability in relative abundances of adult bluefin tuna both inside and outside areas suitable for spawning will be compared, and potential drivers of interannual variability in spawning effort and migration times will be assessed.

Benefits
The benefits of this project will be directly applicable to bluefin tuna stock assessments conducted by PIs on this project through ICCAT. By more accurately accounting for environmental influences that affect catchability we will be able to produce an improved CPUE index that better reflects true abundance. As the only known spawning area for western bluefin tuna, the Gulf of Mexico is a key habitat, and estimates of relative abundance from this area are of paramount importance.
Through collaboration with NOAA-NMFS stock assessment scientists, all of whom currently represent NOAA-NMFS at ICCAT meetings, we will evaluate the effects of including environmental and catchability parameters into an existing abundance index. As this species is intensively managed, with significant United States involvement, development of accurate population indices is essential for effective management. Spawning stock biomass is currently low compared to historical levels, and a rebuilding plan has been adopted. However, there is still some uncertainty regarding the maximum exploitation level which would still allow stock recovery. Refinement of existing indices will enhance confidence limits around past stock trends, and allow improved prediction of future responses. Although bluefin tuna will be examined initially, these methods may be extended to examine other species, such as yellowfin and bigeye tuna, and swordfish.

Results from this project will be communicated to the broader stock assessment community through the framework of ICCAT. By collaborating with NOAA-NMFS stock assessment scientists who contribute to informing stock management decisions, this project contains a direct mechanism for communicating results to a wide range of stakeholders.

Deliverables
Deliverables from this project will include:

1) Habitat suitability and catchability models for bluefin tuna, and other large pelagic species caught on commercial longlines in the GOM,

2) Development and assessment of new experimental indices of adult bluefin tuna abundance in

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**Figure 1:** The Gulf of Mexico larval bluefin tuna index (top), and U.S. pelagic longline adult index (after Anon, 2010)
the GOM, corrected for environmental and gear factors,
3) Publication of results in the ICCAT Collective Volume of Scientific Papers, and in the
peer-reviewed literature,
4) Presentation of results to the stock assessment community at ICCAT workshops, and other
international scientific symposia.

Outputs from this project will thus contribute directly to enhancing stock assessment indices through
incorporation of environmental variables; a major objective of the FATE program.
References


Teo, S.L.H., Boustany, A.M., Block, B.A. (2007) Oceanographic preferences of Atlantic bluefin tuna

Teo, S.L.H., Block, B.A. (2010) Comparative influence of ocean conditions on yellowfin and Atlantic