Integrating Survey-Based Habitat Models into the California Swordfish Fishery Dynamic Management Tool

INTRODUCTION AND BACKGROUND

Maintaining sustainable seafood harvest while minimizing bycatch is a continuing challenge for fishermen and fisheries managers. This project will support the long-term reduction of bycatch by developing tools that:

(1) Are flexible to changing bycatch reduction objectives or criteria (e.g., ensuring bycatch remains below potential biological removal (PBR) levels as population sizes change),
(2) Are capable of analyzing trade-offs among bycatch risk across multiple protected species
(3) Consider economic sustainability by considering impacts of bycatch reduction on the likelihood of catching target species, and
(4) Are flexible enough to be used in multiple fisheries.

In the proposed project, our project team will address these objectives by integrating a series of predictive, dynamic catch and bycatch probability models of target and non-target (bycatch) species for the California swordfish fishery. We will make these predictions available to managers and fishermen in near-real-time via EcoCast, a mobile application (App) developed by our team in collaboration with The Nature Conservancy (TNC).

The California Swordfish Fishery

The California drift gillnet (DGN) fishery is a limited entry fishery that primarily targets swordfish (*Xiphias gladius*) in Federal waters along the US West Coast. The North Pacific stock of swordfish is healthy and sustainable (Brodziak & Ishimura 2010) and harvest of this population meets continued US demand for swordfish. Off the US West Coast, drift gillnet (DGN) fishing is currently one of the only means of harvesting this target species in densities that are economically profitable for fishermen (Leet et al. 2001). However, bycatch of non-target species is common in gillnet gear, resulting in both ecological and economic impacts (Gilman et al. 2008a, Patrick & Benaka 2013, Martin et al. 2015). Bycatch wastes ecological resources, as well as profitable fishing time (Gilman et al. 2008b) Further, bycatch of endangered species such as sperm whales (*Physeter macrocephalus*) and leatherback sea turtles (*Dermochelys coriacea*) has resulted in repeated legal action and widespread fishery closures in response to protection under the Endangered Species Act (ESA). For example, a closure, enacted in 2001 to protect leatherback sea turtles (the Pacific Leatherback Conservation Area), encompasses 596,000 km^2 of historical fishing grounds and greatly

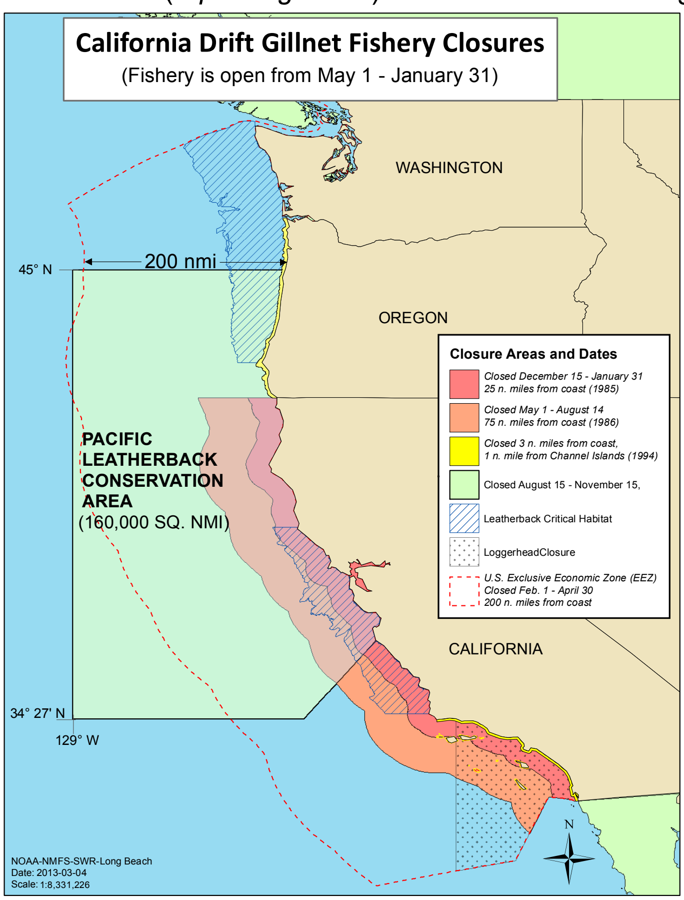

Figure 1. Current closures of the CA drift gillnet fishery. Image credit: NOAA.

restricts the fishery during three of the most productive months of fishing (Federal Register 2001) (Figure 1). As a result, the DGN fleet size has been reduced, and catches have dropped from 2,300 metric tons of swordfish at the peak in 1982, to less than 200 metric tons of swordfish in recent years (Pacific Fishery Management Council 2012).

The DGN fishery is regulated by the Pacific Fishery Management Council (hereafter 'the Council'). The National Marine Fisheries Service (NMFS) West Coast Regional Office is responsible for coordinating and enacting regulations put forth by the Council. Together, the Council and the West Coast Regional Office are charged with meeting environmental mandates (e.g., the Endangered Species Act, Marine Mammal Protection Act) while also managing for ecologically and economically viable fisheries. They are considering whether the protected species mandates can be met with reduced DGN closures because of the negative economic impact closures are having on fishermen, as well as considering alternative gear types, such as deep-set longlines, that may reduce bycatch. Three experimental fishing permits (EFPs) were approved by the Council at the March 2015 Council meeting, with more likely to follow. Additionally, the Council is considering the use of 'hard caps' in the DGN fishery. Hard caps would set the number of individual protected species interactions allowed in a season before the fishery must either be shut down for the season or be markedly reduced (e.g., allowed to operate only in limited areas). For example, hard caps in a year might be set at 2 leatherback turtles, 1 sperm whale, and 10 short-beaked common dolphins (*Delphinus delphis*) across the entire fleet. This could further limit the fishery without a tool to help fishermen determine which areas to avoid to avoid hard-capped species.

EcoCast

In collaboration with the Southwest Fisheries Science Center (SWFSC) and DGN fishermen, and the Council's Highly Migatory Species Management Team (see Support Letters), we are currently developing models and a mobile application called '**EcoCast**' for the California swordfish fishery. As part of EcoCast, we are developing models that predict the catch and bycatch probabilities of key species in near-real-time. These species include: the primary target catch species (swordfish); leatherback sea turtles; California sea lions (*Zalophus californianus*), another protected species; and another bycatch species of concern, blue sharks (*Prionace glauca*). We are integrating fishery dependent (DGN on-board observer data) and independent data (satellite tracking data of bycatch species) with environmental information (e.g.,

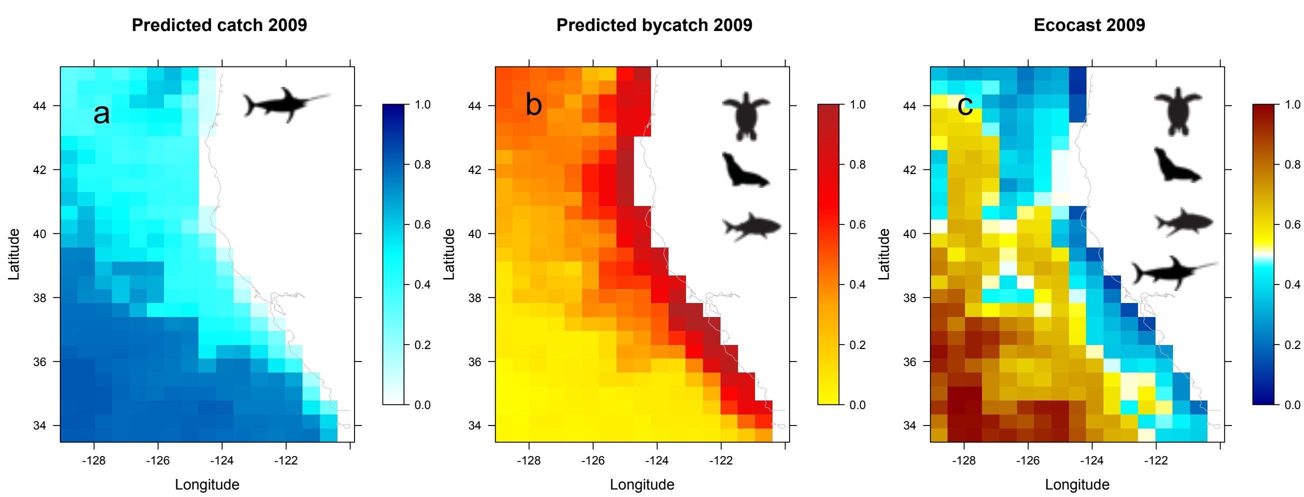

Figure 2. EcoCast model (Hazen et al. in prep). The model represents a fixed temporal extent (June 2009) in which managers and fishermen can identify (a) predicted catch, (b) predicted bycatch and (c) how those two interact across space in this single time frame to understand how they are spatially segregated. Catch and bycatch scales from 0-1, low to high respectively

bathymetry, sea surface temperature, upwelling indices) to characterize habitat of key species and predict their distribution under current environmental conditions. This work, currently funded by grants from NASA's Research Opportunities in Space and Earth Sciences (ROSES) Program and NOAA's Bycatch Reduction and Engineering Program, is resulting in catch and bycatch probability models that highlight **where bycatch species habitat occurs** and where this habitat is likely to **overlap with target catch species** habitat (Figures 2, 3).

One of the limiting factors of this approach, however, is that we do not have data needed to produce models for all species caught in the DGN fishery, many of which are rare or difficult to observe. In our current work, we are integrating data from satellite tracking and on-board fishery observers, however existing satellite-tracking data focus on only a few species, hampering our ability to apply near-real-time management tools for this fishery across all species of concern. Cetacean sighting data, collected during SWFSC systematic shipboard surveys, exist for a large number of cetacean species that are also of bycatch concern in the drift gillnet fishery. Predictive habitat models have been developed from this dataset (Barlow et al. 2009; Becker et al. 2010, 2012; Forney et al. 2012; Becker et al. 2014) and could be modified to be readily integrated into our current work to increase the relevant species included in EcoCast. Some species, however, are difficult to observe on ship-based cruises and are data limited, particularly beaked whales that make long dives and are rarely at the surface. Fishermen who are on the water regularly report seeing many data-limited species; such opportunistic sightings can be harnessed to increase the data available for determining the habitat of rare or difficult to observe species using techniques rapidly being developed for citizen science.

OBJECTIVES

With funding from California Sea Grant, we aim to fill the data gaps above as well as ensure the flexibility of EcoCast to other fishing gears. Our resulting objectives are three-fold:

(1) To develop bycatch probability models and coincident error predictions for cetacean species using sightings data collected from shipboard surveys, and integrate these with models already under development for target catch species (swordfish) and other key bycatch species (leatherback sea turtles, sea lions and blue sharks).
(2) To expand the EcoCast opportunistic sightings application via a workshop with swordfish fishermen to ensure its widespread use and utility for the fleet.
(3) To ensure EcoCast's flexibility for additional swordfish gear types under EFPs and potential hard caps.

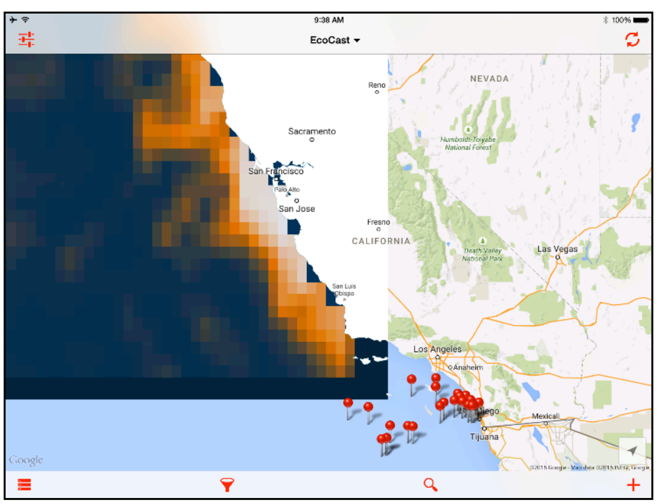

Figure 3. Image of the beta version of a near-real-time dynamic bycatch probability map within the EcoCast mobile application.

APPROACH AND METHODS

We have created a beta **EcoCast** app that collects opportunistic sightings data, and will soon make dynamic bycatch probability models available to managers and fishermen in near-real-time. We have produced draft bycatch probability models for blue sharks, California sea lions, and leatherback turtles by integrating satellite telemetry data and on-board fishery observer data (Figure 2). This information will be available to managers and fishermen via EcoCast, a mobile (e.g., smartphone and tablet) application being developed in collaboration with The Nature Conservancy

(Figure 3); this builds upon their existing application for the West Coast groundfish fishery (eCatch; www.ecatch.org). Sea Grant funds will allow us to include additional critical species in the models by integrating cetacean density data from ship-based surveys, provide capacity for further development of the EcoCast App, and ensure the flexibility of EcoCast for additional swordfish gear types. Below we detail our approach and methods for each of these objectives:

(1) Create bycatch probability models for cetacean species using shipboard survey-collected data. We will use two data types to create predictive habitat models: (1) cetacean sighting data from systematic shipboard surveys, and (2) observer data from the NOAA Drift Gillnet On-Board Observer Program. In addition to sperm and humpback (*Megaptera novaeangliae*) whales, which are protected species, dolphins with the highest DGN bycatch incidents include short-beaked common dolphins, northern right whale dolphins (*Lissodelphis borealis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), long-beaked common dolphins (*D. capensis*), and Risso's dolphins (*Grampus griseus*). Sighting data collected during eight systematic SWFSC shipboard surveys provide sufficient sample sizes to create predictive habitat models for these seven species. Through our partners, we currently have these data in-hand (summarized in Table 1, also see Support Letters). The SWFSC shipboard survey data provide the most comprehensive sightings data for cetacean species in the California Current region, and the NOAA observer dataset covers approximately 21% of all DGN fishery sets since the observer program began in 1990.

Table 1. Data sets in hand. Abbreviations: National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC).

Data type	Data source	Species	Data quantity	Years of available data
Fishery observer data	NMFS	All catch and bycatch species	~21% observer coverage	1990-2013
Systematic ship survey data	SWFSC	Sperm whales	N = 115	1991-2014
Systematic ship survey data	SWFSC	Humpback whales	N = 601	1991-2014
Systematic ship survey data	SWFSC	Short-beaked common dolphins	N = 930	1991-2014
Systematic ship survey data	SWFSC	Northern right whale dolphins	N = 130	1991-2014
Systematic ship survey data	SWFSC	Pacific white-sided dolphins	N = 217	1991-2014
Systematic ship survey data	SWFSC	Long-beaked common dolphins	N = 141	1991-2014
Systematic ship survey data	SWFSC	Risso's dolphins	N = 220	1991-2014

We will create models using each dataset (survey and observer data), and the work will occur in three steps (Figure 4). (1) We will use sightings data from the shipboard surveys and concurrent remotely-sensed and regional ocean modeling system (ROMS) oceanographic data to develop predictive **habitat-based density models** for the seven cetacean species. This will give us models of where bycatch species are likely to occur in space and time based on environmental conditions. The SWFSC survey data were collected during the summer/fall

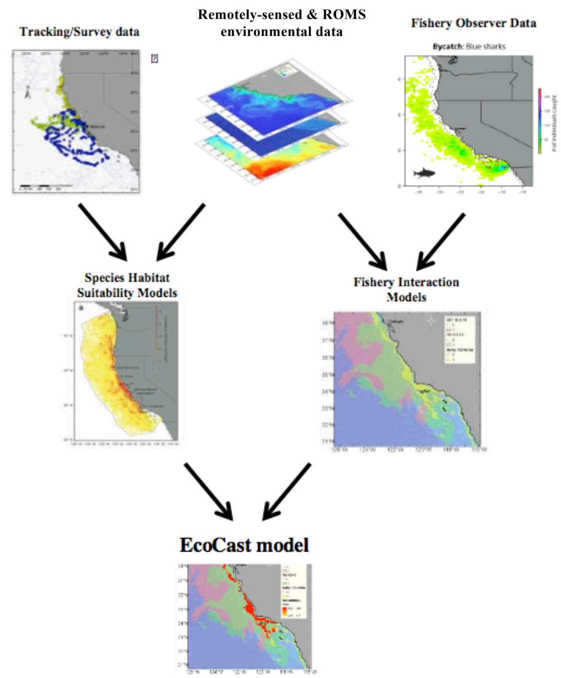

Figure 4. EcoCast modeling work flow schematic.

(roughly late June to early December) and overlap the majority of the swordfish fishery (1 May through 31 January). As part of this project, we will explore the capability of the models to extrapolate to earlier (May) and later (January) time periods. (2) We will use observer data, which includes bycatch events of cetacean species, and concurrent remotely-sensed oceanographic data to create **fishery interaction models** based on both fishing effort and environmental conditions. From this, we will be able to determine if particular environmental conditions are associated with bycatch events (fishery interactions) for our study species. (3) We will combine the models in a hierarchical framework to create a single **EcoCast model of bycatch probability** that gives the probability of bycatch across the fishery landscape (see Figure 3), giving managers insight into where high bycatch is likely to occur. This will be combined with catch probability models for swordfish already under development to show how cetacean species bycatch overlaps with regions of high swordfish catch, the primary economic driver of the fishery. Using near-real-time remotely-sensed and modeled oceanographic data, the EcoCast model can then be applied to current environmental conditions to predict bycatch and catch probability in near-real-time. The near-real-time model can be used as a dynamic management tool to define open and closed fishing areas, and/or as a voluntary tool used by fishermen to reduce bycatch. Each of these steps is described in greater detail below.

Step 1. Habitat-based Density Prediction Models: NOAA Southwest Fisheries Science Center (SWFSC) has conducted 8 systematic ship surveys along the U.S. West Coast between 1991 and 2014. The survey data have been used to develop cetacean habitat models by incorporating physical and biological oceanographic data collected *in-situ* during surveys (Barlow et al. 2009, Becker et al. 2010, Forney et al. 2012, Redfern et al. 2013). Given the time and expense of collecting and processing *in-situ* oceanic data, near-real-time and forecast predictions are only feasible through the use of broadly available measures, such as remotely-sensed and regional ocean model data. In a recent feasibility study, Becker et al. (2012) demonstrated the near-real-time and forecast capabilities of habitat models based on remotely-sensed and modeled oceanographic data (Figure 5). This approach will be used to develop the habitat models and apply predictive models for the EcoCast app.

Remotely-sensed and ocean circulation model data. Remotely-sensed oceanographic datasets used to inform habitat-based density models will include sea surface temperature (SST), an indicator of ocean structure and upwelling; chlorophyll-*a* concentration (chl-*a*), a proxy for primary productivity; sea surface height anomaly (SSHa), which identifies oceanographic features of potential biological importance such as fronts and eddies; geostrophic current flows (zonal, meridional); eddy kinetic energy (EKE), an indicator of mesoscale oceanographic processes; and wind strength and direction. Additionally, we will include bathymetric depth, slope, and aspect derived from ETOPO1 (Amante and Eakins 2009), a 1 arc-minute global-relief model. We will obtain these variables at the highest spatial and temporal resolutions currently available from multiple satellite remote sensing platforms, via the ERDDAP data portal hosted by the Southwest Fisheries Science Centers' Environmental Research Division (coastwatch.pfeg.noaa.gov/erddap/). These remotely-sensed variables have been widely used in habitat modeling for cetaceans and other pelagic marine predators, providing invaluable information characterizing the preferred physical environment of focal species (Becker et al. 2010, 2012; Pikesley et al. 2013).

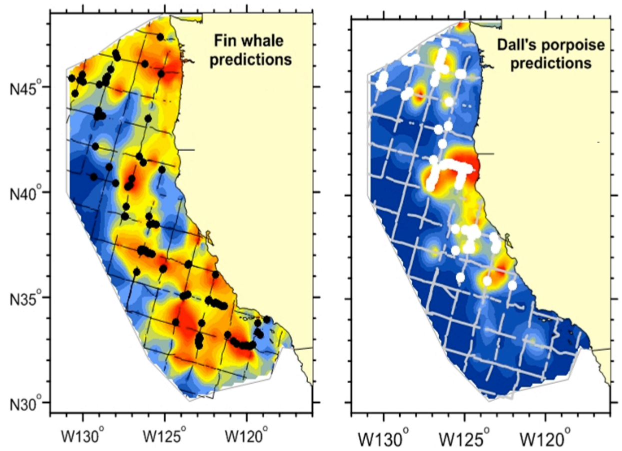

Figure 5. Demonstrated success of predictive habitat-based density models using near-real-time satellite data. Predicted density estimates for fin whale (left panel) and Dall's porpoise (right panel) based on daily habitat-based model predictions over the course of the survey period (July-November, 2008). Highest predicted species densities are shown in red and orange. Black dots show actual 2008 sighting locations, Black lines (fin whale) and white lines (Dall's porpoise) show actual effort for the entire 2008 survey. Predictions are shown for the SWFSC study area (solid line). From Becker et al (2012).**Figure 2.** Beta version of

Additionally, ocean circulation models such as the Regional Ocean Modeling System (ROMS) can provide historical estimates and forecast predictions of relevant habitat variables. The Regional Ocean Modeling System (ROMS) is an open source ocean model that is widely used by the oceanographic community and has been used in diverse applications. A historical reanalysis is available beginning in 1980 and a near real-time system (typically one-day lag) is maintained by researchers at UC Santa Cruz. The utility of the ROMS model for EcoCast is two-fold: (i) it will provide environmental data reliably and at increased temporal and spatial resolution for "nowcasts" (e.g., near-real-time), and (ii) it will enable use of sub-surface predictor variables in habitat models. Satellite data is often patchy due to cloud cover, especially in the coastal zone, and the spatial and temporal resolutions of habitat models are consequently limited by data availability. Furthermore, sub-surface information provided by the ROMS model can be used to calculate ecologically important parameters such as mixed layer depth and thermocline depth, which have proven in some cases to be better than surface data for predicting top predator habitat (Dransfield et al. 2014). Specifically, we will use a California Current System configuration of ROMS (Moore et al. 2013), which covers the coastal ocean to approximately 1000 km offshore, and extends from the Canadian border in the north to midway down the Baja Peninsula in the south. Model resolution is 0.1° in the horizontal, with 42 vertical levels at variable depths, and output is recorded every 6 hours. Accuracy of the ocean state is improved by assimilating available data into the model, including remotely-sensed temperature, salinity, and sea surface height satellite data, as well as *in-situ* hydrographic data from ships, gliders, and profiling floats.

Habitat-based density models. The habitat-based density models will be developed using a Generalized Additive Modeling (GAM; Hastie and Tibshirani 1990) framework. GAMs have performed very well on similar habitat modeling projects that used SWFSC survey datasets, and resulting models have been extensively validated (Barlow et al. 2009; Becker et al. 2010, 2012; Forney et al. 2012; Becker et al. 2014). GAMs will be developed in the R 'mgcv' package using restricted maximum likelihood (REML) to optimize the parameter estimates. To create samples for modeling, the SWFSC survey transects will be divided into continuous-effort segments of approximately 5 km as described by Becker et al. (2010). The number of individuals detected on each segment will be modeled as the response variable, using a Tweedie error distribution to account for overdispersion in the data. Each of the seven species-specific models will include a suite of potential predictor habitat variables derived from remotely-sensed or ROMS datasets described above.

Density (number of animals per km^2) will be estimated by incorporating the model results into the standard line-transect equation (Buckland et al. 2001):

$$D_i = (\frac{n_i \cdot s_i}{A_i})$$

where *i* is the segment, *n* is the number of sightings, *s* is the average group size, and *A* is the effective area searched:

$$A = 2 \cdot L \cdot ESW \cdot g(0)$$

where *L* is the length of the effort segment, *ESW* is the effective strip half-width, and *g(0)* is the probability of detection on the transect line. Segment-specific estimates of both *ESW* and *g(0)* will be incorporated into the models based on the recorded viewing conditions on that segment using coefficients estimated by Barlow et al. (2011) for *ESW* and Barlow (2015) for *g(0)*. The detection parameters are thus intrinsic to the model itself, and provide a distinct modeling advantage since factors affecting detectability do not have to be specifically accounted for when making dynamic predictions. The best model for each species will be selected using a variety of performance metrics including the percentage of explained deviance, root mean squared error, observed to predicted density ratios, and visual inspection of predicted and observed distributions (Forney et al 2012). Using near-real-time environmental data, model predictions of cetacean density can then be made at 5-km resolution within the study area and incorporated into the EcoCast models as described in Step 3 below.

Step 2. Fishery Interaction Modeling: In Step 2, we will construct models by using fishery-dependent data and environmental parameters, again applying a GAM framework. GAMs have been used successfully to relate bycatch events to environmental data, and to describe the environmental features that may lead to higher interaction with fishing gears (Zydelis et al. 2011). Fishery observers are present for approximately 21% of the DGN fishing trips each season and record catch and bycatch, location, and a number of other variables for each set. Each trip lasts approximately 10 days and consists of between an average of 4-5 individual sets. For fishery interaction models, the presence or absence of bycatch species within each unique set will be modeled as the response variable, again using a Tweedie error distribution to account for overdispersion in the data. Additionally, we will use 'set' as a random effect with models to account for potential lack of independence between sets within each fishing trip, thus using a mixed model approach (Zuur et al. 2009). From this, we can characterize the occurrence of bycatch based on its association with specific environmental variables through time. Model predictions of cetacean bycatch can then be made within the study area and incorporated into the EcoCast models as described in Step 3 below. By determining not only where fishery interaction is likely to occur, but also where it is likely to occur in higher levels in relation to specific environmental variables, we can refine the importance of management actions to reduce bycatch.

Step 3. EcoCast Model Integration: Finally, we will integrate the two models above to determine where animals are likely to be found (through habitat-based density models) and where they are likely to be caught (through fishery interaction); from the integrated model we can predict bycatch in near-real-time scenarios using the remotely-sensed and ROMS data described above. For the focal bycatch species, we will create a bycatch probability model using a similar approached as outlined in Zydelis et al. (2011). For each bycatch species i, we will create an algorithm that determines the probability of bycatch (*Pi*) based on significant environmental variables and predicted habitat suitability:

$$P_i \sim H_i + B_i + \text{error}$$

where H_i is the predicted habitat-based density models of species *I* (from Step 1), and B_i is the predicted fishery interaction of species *i* (from Step 2). We will create a matrix of bycatch probabilities for each species using the models developed above, and weight the models by their spatial error. We can integrate the bycatch species layers with swordfish catch probability models already under development. In doing so, each species can be given a risk weighting determined by a combination of the economic cost to the fishery and management concern which can be adjusted as conditions in the fishery change, e.g. if a hard cap is approached. Further, we can determine, for example:

- The overall probability of bycatch by summing bycatch probabilities (sum of *Pi*) through time based on changing environmental conditions;
- Where areas of high catch and low bycatch coincide through time using spatial metrics such as Moran's I (Fortin et al. 2002).
- Most importantly, we can also predict the probability of bycatch in near-real-time using the most currently available remotely-sensed and ocean circulation model data.

Temporal scale of the final near-real-time outputs will be determined according to such variables as temporal resolution of remotely-sensed oceanographic data, fishing effort information, and how the model fits with management objectives. Finally, cetacean bycatch probability models will be incorporated into the EcoCast mobile application that is currently under development via funds from NOAA's Bycatch Reduction and Engineering Program that will make bycatch probability maps available to fishermen and managers in near-real-time (Figure 3).

(2) Expand use and utility of the EcoCast opportunistic sightings application. With funding from NOAA's Bycatch Reduction and Engineering Program, we have also developed a beta version mobile application called 'EcoCast' that allows users to record opportunistic sightings of marine species such as cetaceans and sea turtles anonymously while on the water; it further serves as a platform for visualizing bycatch risk (Figure 6). At the November 2014 Pacific Fishery Management Council meeting, we introduced the EcoCast App to commercial DGN

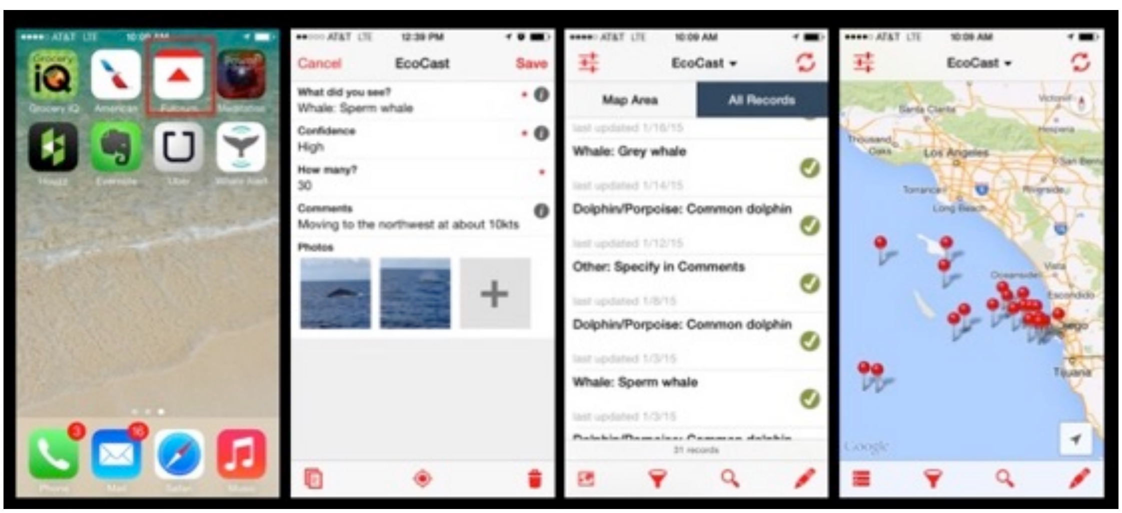

Figure 6. The EcoCast opportunistic sightings application. The application is designed to quickly and easily collect georeferenced information on non-target species, abundance, and observer confidence, as well as photos.

fishermen at the Highly Migratory Species Advisory Subpanel meeting. To maintain trust within the fishing community, we have restricted use of the App mainly to commercial fishermen, but recreational charter captains and spotter plane captains were also interested in using the App. At this time, approximately half of the active DGN fishing fleet have downloaded and been trained to use the App. As part of the application, fishermen can record the species they see within range of their vessel. They also record their level of confidence in species identification (high, medium, low), the number of individuals seen, and any additional comments or photos. The App automatically records their location from the internal GPS of their smartphone or tablet, and while out of cellular range, data input is cached and automatically uploaded when back within cellular signal. To date, cetacean sighting records have included more than 70 sperm whales, 5 killer whales and 6 pilot whales, many with accompanying photos, demonstrating the utility of this approach (Figure 6).

With Sea Grant funds, we will hold a workshop with fishermen (likely to be held in conjunction with a Pacific Fishery Management Council meeting or Highly Migratory Species Team Meeting) to garner increased use of the App, and identify areas of improvement for the app and the broader EcoCast tool as it continues to be developed. We can use the opportunistically collected data as a validation set for models above. Further, as additional data are collected in the future, we can examine the use of presence-only models based on these data, particularly during space and time periods when survey data are lacking. To avoid bias associated with sightings reported where vessels are found, models can allow for prediction beyond the area/times of the input data, and verified using independent datasets (e.g. existing survey or observer), similar to Becker et al (2014). This opportunistically collected data can provide increased accuracy of predictions of data-limited species distributions for future integration into the EcoCast product, as well as engage fishermen in the scientific data collection that is part of the larger fishery management process.

(3) Maintain flexibility for additional swordfish gear types under EFPs and potential hard caps. Over the course of the project, we will attend PFMC and Highly Migratory Species Management Team (HMSMT) meetings, and give presentations on our progress to receive feedback on how this tool can best be adapted to meet the Council's objectives. Additionally, we will continue to interact formally and informally with managers and fishermen to incorporate comments and suggestions to increase EcoCast's utility and flexibility, particularly as the Pacific Fishery Management Council moves towards shifting the swordfish fishery to other gear types. Three experimental fishing permits (EFPs) were approved at the March Council meeting, including one for pelagic longline gear and two for deep set buoy gear. We will work directly with EFP permit holders and the HMSMT to determine how EcoCast can be applied to these gear types over the next fishing season. We will continue to work with the HMSMT to determine how EcoCast could be applied to assessing/adjusting bycatch hard caps and/or closed areas in future management scenarios. The Council is currently considering hard cap scenarios and is expected to determine a final management plan for hard caps within the next year.

OUTCOMES AND DELIVERABLES

This project will use best available data and scientific techniques to support decision-making in the California swordfish fishery. This work will: (1) Aid in determining where and when cetacean species are likely to occur to improve fishery sustainability; (2) Allow managers to consider regulations that are economically and ecologically sustainable, while allowing fishermen to target areas with the least ecological and economic costs; (3) Improve the near-real-time management of this fishery, and do so in a way that is adaptive to changes in environmental conditions; and (4) Result in greater sustainability of marine fisheries, starting with the drift gillnet fishery but also providing a toolbox that can be used in other fisheries, resulting in greater sustainability of California fisheries.

The outcomes related to our specific objectives follow.

(1) Create bycatch probability models for cetacean species using shipboard survey data.

- Model outcomes:
    - Habitat-based density models that relate density and distribution to oceanographic conditions for seven cetacean species

- Fishery interaction models that relate cetacean bycatch to oceanographic conditions for seven cetacean species
  - Bycatch probability models for the seven cetacean species that integrate the habitat-based density models and fishery interaction models together to show where animals are most likely to be *and* where they are most likely to be caught; these models will use near-real-time environmental data to create model forecasts.
  - Two peer-reviewed publications describing the models above
- Management outcomes:
  - The modeling efforts above will bring additional species of concern into EcoCast, a tool that is currently under development to inform fisheries management
  - Models will support decision making processes on the part of the Council via our collaboration with the Highly Migratory Species Management Team (see Support Letters)
  - Models can be used voluntarily by fishermen to reduce bycatch on the water, and will be particularly useful in hard caps implemented in the DGN fishery (see Support Letters)

(2) Expand EcoCast opportunistic sightings mobile application.

- Scientific outcomes:
  - Expand use of the EcoCast opportunistic sightings mobile App to 75% of the DGN fleet
  - Increase sightings to at least 200 entries in the 2016-17 fishing season
  - Use data collected by fishermen for bycatch probability model validation
- Management/outreach outcomes:
  - Determine changes/additions to the App that will increase use of the App by fishermen and maintain long-term use by the fishing community (e.g., inclusion of sea surface temperature, etc.)
  - Integrate fishermen-collected data into the scientific process
  - Provide a key outreach tool to empower fishermen to engage with the scientific process that is managing their fishery

(3) Maintain flexibility for other swordfish gear types under EFPs and potential hard caps.

- Management/outreach outcomes:
  - Adapt models to other fisheries both during experimental gear trials, and if one of the gear types is approved for use as a commercial tool
  - If hard caps are put into place, use the models to help fishermen to avoid areas where hard-capped species are likely to occur in order to maintain a viable fishery by limiting protected species bycatch

RELATIONSHIP TO CALIFORNIA SEA GRANT GOALS

As articulated in Safe and Sustainable Fisheries and Seafood Supply Goal 1, sustainable use of California's fishing resources is important for a healthy marine ecosystem, as well as sustainable socioeconomic communities. Demand for swordfish in the US remains high and is increasing, and the North Pacific stock of swordfish is healthy and sustainable. However, drift gillnet fishing is one of the only means of harvesting this target species in densities that are economically profitable for fishermen, and a consequence is that bycatch of non-target species is common. Nonetheless, the highly regulated DGN provides more sustainable swordfish than most other sources - indicating the importance of ensuring a viable US fishery. Providing an economically viable fishery is key to both the livelihoods of fishermen and to reducing impacts on overharvested swordfish stocks elsewhere. Bycatch wastes ecological resources, as well profitable fishing time, resulting in both ecological and economic impacts. Further, bycatch of protected species such as leatherback sea turtles has resulted in repeated legal action and large-scale fishery closures, which a dynamic management tool could help minimize. Our project will not only provide a tool to promote sustainable fisheries, we will provide managers the ability to simultaneously evaluate the impact of spatial management decisions on both fishermen and bycatch species (Strategy 1-3). Further, we are working directly with stakeholders (fishermen) and managers (Strategy 1-2) to help them apply techniques to reduce bycatch of a number of species, including protected and endangered species. By directly involving fishermen and manager partners, we further meet the CASG cross-cutting theme to provide 'the best available scientific knowledge to stakeholders who need it.'

PROJECT TEAM AND TIMELINE

In addition to holding expertise in the fields of fisheries ecology, oceanography, spatial modeling and predator ecology, members of our research team are actively engaged with the Highly Migratory Species (HMS) Management Team and HMS Advisory Subpanel, which provide management alternatives to the Pacific Fisheries Management Council (PFMC), the managing body of the drift gillnet fishery. Below we outline the contribution of individuals to the project, including student role, and the project timeline.

(PI) Sara Maxwell: As Project PI, Dr. Maxwell will be responsible for project coordination, data management (as per agreement included in the proposal), advising the student trainee, and outreach (including workshop planning) with fishermen, the Council and the Highly Migratory Species Management Team. She will work with M. Stevens (supporting partner; see below and Support Letter) from The Nature Conservancy to coordinate the workshop and integrate changes to the EcoCast App.

(Co-PI) Elizabeth Becker: Dr. Becker will be responsible for development of habitat-based density prediction models (including obtaining oceanographic data with help from Dr. Scales), and aid with development of bycatch probability models.

Student Trainee: The student trainee (Ph.D. student) on the project will be responsible for the development of bycatch probability models (including obtaining oceanographic data with help from Dr. Scales), under the guidance of Dr. Maxwell. S/he will also aid in integrating these models with other catch/bycatch probability models that are part of EcoCast, and participate in outreach components of the project.

(Co-PI) Kylie Scales: Dr. Scales will be responsible for coordinating and obtaining remotely-sensed and ocean circulation model data used for the various species models. Additionally, she will be responsible for integrating cetacean bycatch probability models with swordfish and other bycatch models in EcoCast.

(Co-PI) Elliott Hazen: Dr. Hazen will be for responsible for aiding Dr. Scales in integrating cetacean bycatch probability models with swordfish and other bycatch models in EcoCast, as well as aiding in incorporation of remotely-sensed and modeled oceanographic variables.

(Supporting partner) The Nature Conservancy: Using funds from a concurrent Bycatch Reduction and Engineering Program (NOAA), Ms. Melissa Stevens and Mr. Matt Merrifield will aid outreach, workshop planning and modifications to the EcoCast application (see Support Letter).

Table 2. Timeline for tasks/deliverables. Primary responsible individual(s) listed in decreasing order of responsibility.

Task/Deliverable	Primary Responsible Individual(s)	Months 1-6	Months 7-12	Months 13-18	Months 19-24
Assemble survey and fishery observer data	E. Becker, S. Maxwell	Already completed			
Obtain remotely-sensed and ocean circulation model data (for survey and observer data)	K. Scales, E. Becker, S. Maxwell, Student Trainee	X			
Create habitat-based density prediction models (survey data)	E. Becker	X	X		
Habitat-based density prediction model validation & selection (survey data)	E. Becker			X	
Create fishery interaction models (observer data)	Student Trainee, S. Maxwell	X	X		
Fishery interaction model validation and selection (observer data)	Student Trainee, S. Maxwell			X	
Integrate models to create bycatch probability models	Student Trainee, S. Maxwell, E. Becker			X	X
Integrate cetacean bycatch probability models with swordfish and other bycatch models in EcoCast	K. Scales, E. Hazen, Student Trainee, S. Maxwell				X
Attend Council/HMST Meetings to present progress and interact with managers and fishermen	S. Maxwell, Student Trainee	X		X	X
Workshop with fishermen to discuss EcoCast opportunistic sightings App	S. Maxwell, Student Trainee, The Nature Conservancy	X		X	
Modification of EcoCast App based on recommendations	The Nature Conservancy		X		
Collection of opportunistic sightings data by fishermen (will occur during primary fishing season)	(Fishermen)		X		X

REFERENCES

Amante C, Eakins BW (2009) ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. Page 19. NOAA Technical Memorandum NESDIS NGDC-24

Barlow J (2015) Inferring trackline detection probabilities (g(0)) for cetaceans from apparent densities in different survey conditions. Mar Mamm Sci DOI: 10.1111/mms.12205

Barlow J, Balance LT, Forney KA (2011) Effective strip widths for ship-based line-transect surveys of cetaceans. NOAA Technical Memorandum NMFS-SWFSC-484, U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA

Barlow J, Ferguson MC, Becker EA, Redfern JV, Forney KA, Vilchis IL, Fiedler PC, Gerrodette T, Balance LT (2009) Predictive modeling of marine mammal density from existing survey data and model validation using upcoming surveys. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-444

Becker EA, Foley DG, Forney KA, Barlow J, Redfern JV, Gentemann CL (2012) Forecasting cetacean abundance patterns to enhance management decisions. Endang Species Res 16:97–112

Becker EA, Forney KA, Ferguson MC, Foley DG, Smith RC, Barlow J, Redfern JV (2010) Comparing California Current cetacean-habitat models developed using in situ and remotely sensed sea surface temperature data. Mar Ecol Prog Ser 413: 163–183

Becker EA, Forney KA, Foley DG, Smith RC, Moore TJ, Barlow J (2014) Predicting seasonal density patterns of California cetaceans based on habitat models. Endang Species Res 23: 1-22

Brodziak J, Ishimura G (2010) Stock assessment of north pacific swordfish (*Xiphias gladius*) in 2009, NOAA Pacific Islands Fisheries Science Center, Administrative Report H-10-01

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to distance sampling: Estimating abundance of biological populations. Oxford University Press, Oxford

Dransfield A, Hines E, McGowan J, Holzman B, Nur N, Elliott M, Howar J, Jahncke J (2014) Where the whales are: using habitat modeling to support changes in shipping regulations within National Marine Sanctuaries in Central California. Endang Species Res 26: 39-57

Federal Register (2001) Endangered and threatened wildlife; sea turtle conservation requirements; taking of threatened or endangered species incidental to commercial fishing operations. In: Administration NOAA (ed), Washington DC, p 44549-44552

Forney KA, Ferguson MC, Becker EA, Fiedler PC, Redfern JV, Barlow J, Vilchis IL, Balance LT (2012) Habitat-based spatial models of cetacean density in the eastern Pacific Ocean. Endang Species Res 16:113-133

Fortin M-J, Dale M, Hoef JV (2002) Spatial analysis in ecology. In: El-Shaarawi AH, Piegorsch WW (eds) Encyclopedia of environmetrics, Vol 4. John Wiley & Sons, Ltd, Chichester, p 2051–2058

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J and others (2008a) Shark interactions in pelagic longline fisheries. Mar Policy 32:1-18

Gilman E, Koybayashi D, Chaloupka M (2008b) Reducing seabird bycatch in the hawaii longline tuna fishery. Endang Species Res 5:309-323

Hastie TJ, Tibshirani RJ (1990) Generalized Additive Models, Vol 43. Chapman & Hall/CRC, Boca Raton

Leet WS, Dewees CM, Klingbeil R, Larson EJ (eds) (2001) California's living marine resources: A status report, Vol. California Department of Fish and Game, Sacramento CA

Martin SL, Stohs SM, Moore JE (2015) Bayesian inference and assessment for rare-event bycatch in marine fisheries: A drift gillnet fishery case study. Ecol Appl 25:416-429

Moore AM, Edwards CA, Fiechter J, Drake JP, Arango H, Neveu E, Grol S, Weaver AT (2013) A prototype for an operational regional ocean data assimilation system. Data Assimilation for Atmospheric, Oceanic and Hydrological Applications, Vol II , L. Xu and S. Park, eds., Springer, chapter 14, p 345–366
Pacific Fishery Management Council (2012) Status of the US west coast fisheries for highly migratory species through 2011: Stock assessment and fishery evaluation, NMFS/PFMC, Portland OR
Patrick WS, Benaka LR (2013) Estimating the economic impacts of bycatch in US commercial fisheries. Mar Policy 38:470-475
Pikesley SK, Maxwell SM, Pendoley K, Costa DP and others (2013) On the front line: Integrated habitat mapping for olive ridley sea turtles in the southeast Atlantic. Divers Distrib
Redfern JV, McKenna MF, Moore TJ, Calambokidis J, DeAngelis ML, Becker EA, Barlow J, Forney KA, Fiedler PC, Chivers SJ (2013) Assessing the risk of ships striking large whales in marine spatial planning. Conserv Biol 27(2):292-302
Zuur A, EN I, Walker N, Saveliev A, Smith G (2009) Mixed effects models and extensions in ecology with R, Vol. Springer, New York
Zydelis R, Lewison R, Shaffer SA, Moore JE and others (2011) Dynamic habitat models: Using telemetry data to project fisheries bycatch. Proceedings of the Royal Society of London Series B-Biological Sciences DOI: 10.1098/rspb.2011.0330