Project Title: EcoCatch: Improving ecological and economic sustainability of marine fisheries using remotely-sensed oceanographic data

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Short Title: EcoCatch: Improving sustainability of marine fisheries

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Proposal Summary:

Balancing sustainable ecological and economic objectives, including reduction of bycatch, is a continuing challenge for fisheries managers. The California drift gillnet (DGN) fishery harvests healthy stocks of swordfish, however, bycatch of non-target species is common, and has resulted in large-scale fishery closures to prevent bycatch despite continued high demand for swordfish.

We have partnered with DGN fishermen and NOAA/NMFS Southwest Regional Office, which is responsible for regulating the fishery, to reduce bycatch while improving fishery sustainability. The objective of this Feasibility Study Project is to evaluate the applicability of **EcoCatch**, a near real-time, multi-species fisheries management tool. Our approach will build on previous NASA-funded projects, TurtleWatch and WhaleWatch. In these projects, researchers couple movement data of protected species with remotely-sensed oceanographic data to successfully reduce bycatch and other human impacts on protected species. We will expand upon this approach by considering both catch and bycatch taxa.

Through EcoCatch we will utilize a number of data types to create catch and bycatch probability models. We will do this by integrating remotely-sensed oceanographic data, fishery observer data and satellite tracking data of key species of ecological and regulatory importance (leatherback turtles, California sea lions, and blue sharks), and ‘crowdsourced’ *in situ* catch and bycatch data from fishermen. This will allow managers to explicitly consider both ecological and economic objectives into a single tool. Managers will be able to consider the tradeoffs between meeting ecological and economic objectives in the DGN fishery, as well as find the regions where both objectives are maximized. Further, by engaging directly with fishermen, valuable data will be added to our models for input and validation and the likelihood of voluntary use of the models prior to regulatory application will also be increased.

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Decision-Making Activity

Balancing sustainable ecological and economic objectives is a continuing challenge for fisheries managers. The drift gillnet (DGN) fishery in California waters is a limited entry fishery that primarily targets swordfish (*Xiphias gladius*) along the US West Coast. The North Pacific stock of swordfish is healthy and sustainable (Brodziak and Ishimura 2010) and harvest of this population meets continued demand for swordfish. In the Pacific, drift gillnet fishing is 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 (Patrick and Benaka 2013). Bycatch wastes ecological resources, as well as profitable fishing time (Gilman et al. 2008). Further, bycatch of endangered species such as 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). Current closures, enacted to protect leatherback sea turtles (the Pacific Leatherback Conservation Area), encompass 596,000 km^2 of historical fishing grounds, and greatly restrict the fishery during three of the most productive months of fishing (Federal Register 2001)(Figure 1). As a result, the productivity of the fishery 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'), one of 8 regional fishery management councils established by the Magnuson-Stevens Fishery Conservation and Management Act of 1976. The National Oceanic and Atmospheric Administration (NOAA)/National Marine Fisheries Service (NMFS) Southwest Regional Office is responsible for coordinating and enacting regulations put forth by the Council. Together, the Council and NOAA/NMFS Southwest Regional Office are charged with meeting environmental mandates (e.g., ESA) while also managing for ecologically viable and economically profitable 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. Currently the Council and Southwest Regional Office make decisions based on piecemeal information from catch statistics and surveys, and lack a tool that is able to integrate data across ecological and economic objectives to make the most informed management decisions.

In collaboration with the NMFS Southwest Regional Office and DGN fishermen (see Support Letters), we will develop a model that predicts in near real-time catch and bycatch of key species for the DGN fishery; swordfish, leatherback sea turtles, as well as a protected species (California sea lions, *Zalophus californianus*) and a bycatch species of economic concern (blue sharks, *Prionace glauca*). We will integrate this data with Earth observations of sea surface temperature, sea height anomalies, upwelling indices, etc., which have been shown to be instrumental in accurately predicting species distribution under current and future conditions in a cost-effective and sustainable manner (Block et al. 2011, Hazen et al. 2012). The resulting model will allow managers to design regulations that are economically and ecologically sustainable, while allowing fishers to target areas with the least ecological and economic costs.

The end-users of our project are the Council, the NOAA/NMFS Southwest Regional Office and the fishermen themselves. Our tool will be developed with guidance from the Council and the Southwest Regional Office to ensure that the tool will be feasible and most effective for use in a management context. Further, fishermen will be involved in the development process, collecting additional data and validating models to ensure the tool meets the needs of fishermen on-the-ground. Our tool will be hosted by NOAA/ NMFS Southwest Fisheries Science Center (SWFSC) initially and will be transferred to the NOAA Southwest Regional Office once the tool has been fully developed.

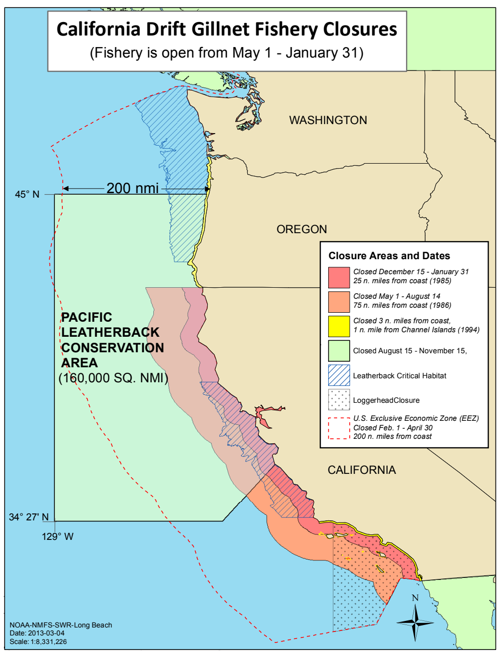
Earth Observations: Satellite products to be used as part of EcoCatch, along with resolution, time periods covered and source.

Variable	Product/Sensor	Grid resolution	Temporal resolution	Temporal coverage	Source
Sea surface height	Merged (Topex/Poseidon, ERS-1/-2, Geosat, GFO, Envisat, Jason-1/-2)	0.3333 deg	1 day	[14-Sep-94 16-Apr-08]	AVISO
Eddy kinetic energy	Merged (Topex/Poseidon,ERS-1/-2,Geosat, GFO, Envisat, Jason-1/-2)	0.3333 deg	7 day	[14-Sep-94 16-Apr-08]	AVISO
Ekman upwelling	Seawinds/QuikSCAT	12.5 km	8 day	[1-Aug-99 10-Apr-08]	NASA/JPL
Sea surface temperature	AVHRR Pathfinder v. 5 (day and night)	4.4 km	5 day	[15-Sep-94 13-Apr-08]	NOAA/NESDIS
	Blended (AVHRR/POES, Imager/GOES, MODIS/Aqua, AMSR-E/Aqua)	11 km	5 day	[4-Jul-02 present]	NOAA/NESDIS
SST gradient	AVHRR Pathfinder v. 5 (day and night)	4.4 km	5 day	[15-Sep-94 13-Apr-08]	NOAA/NESDIS
Chlorophyll-*a* concentration	SeaWiFS/Orbview-2	8.8 km	8 day	[9-Aug-98 10-Apr-08]	NASA/GSFC
	MODIS/Aqua	4.4 km	8 day	[Jul-02 present]	NASA/GSFC
Bottom depth	SRTM30_PLUS v.6.0 digital bathymetry	0.0083 deg	--	Fixed	UCSD/SIO
Bottom slope	Derived from bottom depth	0.0083 deg	--	Fixed	UCSD/SIO
Bottom aspect (northness, eastness)	Derived from bottom depth	0.0083 deg	--	Fixed	UCSD/SIO
Distance to shelf break (200m isobath)	SRTM30_PLUS v.6.0 digital bathymetry	0.0083 deg	--	Fixed	UCSD/SIO

Science-Technical

Bycatch Issues in the Drift Gillnet Fishery

Fishery managers struggle to enact management measures that balance ecological sustainability with economic viability. In ideal scenarios, this ecological-economic balance results in sustainable fisheries that maximize profitable target catch, while minimizing catch of non-target species (Maxwell et al. 2012). Reducing catch of non-target species, or bycatch, is a key management objective because bycatch results in ecosystem impacts (Patrick and Benaka 2013). Bycatch has economic impacts as it wastes profitable fishing time, as well as causing safety concerns for fishermen (Gilman et al. 2008). Additionally, fisheries managers are tasked with meeting environmental mandates. For fisheries management, this often means more concerted efforts to reduce and ideally eliminate bycatch of species protected under laws such as the Endangered Species Act or the Marine Mammal Protection Act (Moore et al. 2009).



At its peak in 1982, the DGN fishery landed over 2,300 metric tons of swordfish, though this has declined to less than 200 metric tons of swordfish in recent years (Pacific Fishery Management Council 2012). Concurrently, bycatch of a number of species has been of concern. Bycatch of blue sharks was estimated at over 15,000 sharks per year in the late 1980s. This number has declined substantially with effort declines in the fishery and changes in fishing practices. However, blue sharks are still one of the most common bycatch species (Carretta and Enriquez 2012). In addition to having a significant ecological impact, blue sharks have no commercial value and result in considerable economic losses for fishermen. Blue shark bycatch results in wasted time to remove blue sharks from the nets, safety risks to fishermen, and target catch is often predated by blue sharks thereby reducing overall target catch (Gilman et al. 2008)DGN fishermen, personal communication).

California sea lions are a protected species under the Marine Mammal Protection Act (MMPA) and 25 incidental capture events were observed in the DGN fishery in 2010, though this number is only reflective of observed sets (approximately 21% of sets); total bycatch is likely closer to 200 animals (Carretta and Enriquez 2012). NMFS is charged with reducing bycatch of marine mammals, including sea lions, to the extent possible in order to comply with the MMPA. Exceeding approved incidental catch rates of sea lions (or the 'potential biological removal', set at 9,200 animals across all anthropogenic mortality sources) authorized under section 101(a)(5)(E) of the MMPA could result in closure of the fishery (NMFS 2000, Carretta et al. 2011). Additionally, sea lions regularly predate target catch caught in the net, resulting in economic losses (DGN fishermen, personal communication).

Finally, leatherback sea turtles are an Endangered Species under the Endangered Species Act. Twenty-four bycatch events of leatherbacks have been observed in the DGN fishery since the observer program began in 1989 (NMFS 2000, Pacific Fishery Management Council 2012). While limits of incidental catch rates of leatherbacks have not been set, the Endangered status under ESA and a number of leatherback-related lawsuits against NMFS has resulted in large-scale closures of the DGN fishery. Current closures, enacted to protect leatherback sea turtles (the Pacific Leatherback Conservation Area), encompass 596,000 km^2 of historical fishing grounds, and restrict the fishery during three of the most productive fishing months of the year (Aug 15-Nov 15), causing significant economic impacts on fishermen (Figure 1**)** (Federal Register 2001).

Objectives

There is an urgent need to reduce bycatch in the DGN fishery, in order to decrease incidental catch of endangered species and restore and maintain the ecological integrity of the system while meeting the economic demand for swordfish and needs of fishermen. Global demand for swordfish is high (Rausser et al. 2009), and providing for an economically viable fishery is key to both the livelihoods of DGN fishery and to reducing impacts on overharvested swordfish stocks elsewhere.

Despite our ever-increasing understanding of the oceanographic environment through Earth observations and our developing ability to predict the habitat of both target and non-target species in space and time, the majority of fishery management tools do not actively employ these spatially explicit tools. We have therefore partnered with DGN fishermen, the Pacific Fishery Management Council and NOAA/NMFS Southwest Regional Office to create a management tool designed to reduce bycatch while supporting fishery viability and profitability. The Council and the Southwest Regional Office have identified the need for integrating habitat information on target and bycatch species, and have a strong interest in the EcoCatch model (see Support Letter). Our model is particularly relevant at this time, as the Council's Highly Migratory Species Management Team will be evaluating impacts of potential changes to management of the DGN over the next year. These potential changes include allowing fishing in areas that are currently closed that would not compromise bycatch reduction strategies for leatherbacks.

The objective of this proposal is to produce a near real-time, multi-species fisheries management tool to support this effort. Our tool, EcoCatch, will integrate remotely-sensed oceanographic data, 'crowdsourced' data from fishers, fishery observer data and satellite telemetry data to create catch and bycatch probability models in order to effectively manage the drift gillnet fishery both ecologically and economically.

Approach

Our approach will build on previous and currently NASA-funded projects, including TurtleWatch (E. Howell, PI: http://www.pifsc.noaa.gov/eod/turtlewatch.php) and WhaleWatch (H. Bailey, PI: http://www.umces.edu/cbl/whalewatch). Their technique is to couple movement data of protected species with remotely-sensed Earth observations to predict where and when animals are likely to be found. These data can then be used to inform where and when human activities such as fishing, Naval operations, shipping, etc. can be safely conducted with least risk to these protected species. The recommendations of TurtleWatch on areas to avoid have successfully helped to reduce bycatch of loggerhead turtles in the Hawaiian longline fishery.

With EcoCatch we will expand upon this approach by combining multiple taxa, and consider both areas to be targeted for target catch *and* avoided for unwanted bycatch. Applying EcoCatch to the California drift gillnet (DGN) fishery as a case study, we will determine near real-time habitat of three bycatch species of ecological, economic and regulatory importance, as well as the habitat of the primary target catch species. From this, we will determine where fishing will have reduced bycatch impacts, while being able to sustain economic gains by maintaining profitable fishing grounds.

Explicitly considering both ecological and economic needs in a single tool will allow managers to consider the tradeoffs between meeting ecological and economic objectives in the DGN fishery, as well as find the regions where both objectives are maximized. This tool could also be adapted to meet the needs of other fisheries, both in the California Current and other regions (e.g., the Northeast Atlantic American lobster fishery, which is working to reduce entanglement of northern right whales in lobster pots). Further, by engaging directly with fishermen who will participate by ‘crowdsourcing’ data from their current fishing efforts, valuable data will be added to our models as input and, later, as model validation. Additionally, fishermen will be more likely to use the models voluntarily once developed if they take an active role in the development process (Jenkins 2007).

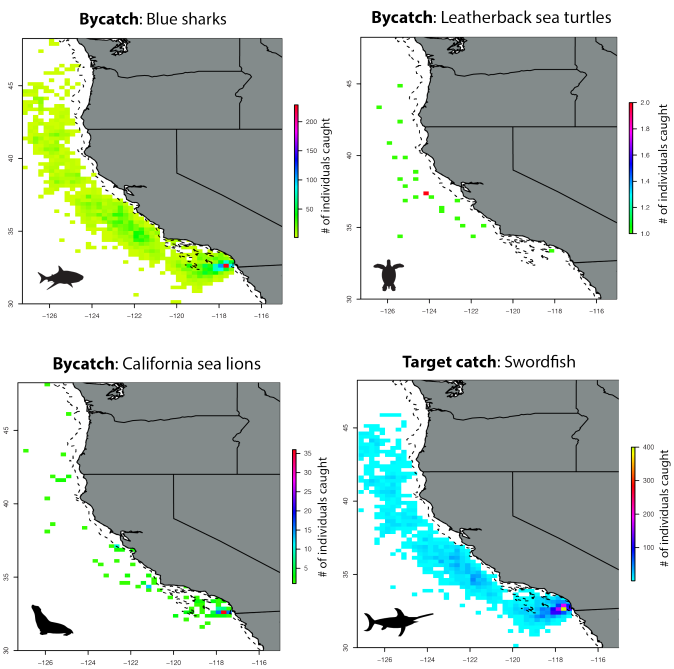


Figure 2. Bycatch and catch events of focal species from 1988-2011; data from the NOAA Drift Gillnet Observer Program.

The use of Earth observations such as remotely-sensed oceanographic data is critical to effectively developing the EcoCatch model and ensuring its sustainability beyond the duration of the project. Furthermore, the use of freely available Earth observations makes the model cost-effective enough for use into the future, and economically feasible as a tool to be used in other fisheries.

Method Overview

We will use two data types to create predictive habitat models: (1) Argos satellite-derived tracking data for the three species (blue sharks, California sea lions, leatherback sea turtles), and (2) observer data from the NOAA Drift Gillnet On-Board Observer Program (Figure 2). Through our partners, we currently have this data in-hand (summarized in Table 1). The satellite tracking datasets represent the largest datasets in the world for these top predator species, 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), Tagging of Pacific Predators (TOPP) project.

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

Satellite tracking	TOPP	Leatherback sea turtles	N = 18	2004-2008
Satellite tracking	TOPP	California sea lions	N = 75	2003-2009
Satellite tracking	TOPP	Blue sharks	N = 144	2002-2009

We will create models using each dataset (tracking and observer data), and the work will occur in three steps (Figure 3). (1) We will use tracking data and concurrent remotely-sensed oceanographic data to determine suitable habitat for the three bycatch study species (blue sharks, California sea lions and leatherback sea turtles). This will give us models of where bycatch species are likely to occur in space and time based on environmental conditions. (2) For both catch and bycatch species, we will use observer data 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 catch and bycatch events (fishery interactions) for our study species. (3) We will combine the two models together to create a single EcoCatch model of catch and bycatch probability that gives the probability of catch and bycatch across the fishery landscape (see Figure 3), giving managers insight into where high bycatch is likely to occur, and how this overlaps with regions of high swordfish catch, the primary economic driver of the fishery. Using near real-time remotely sensed oceanographic data, the EcoCatch 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.

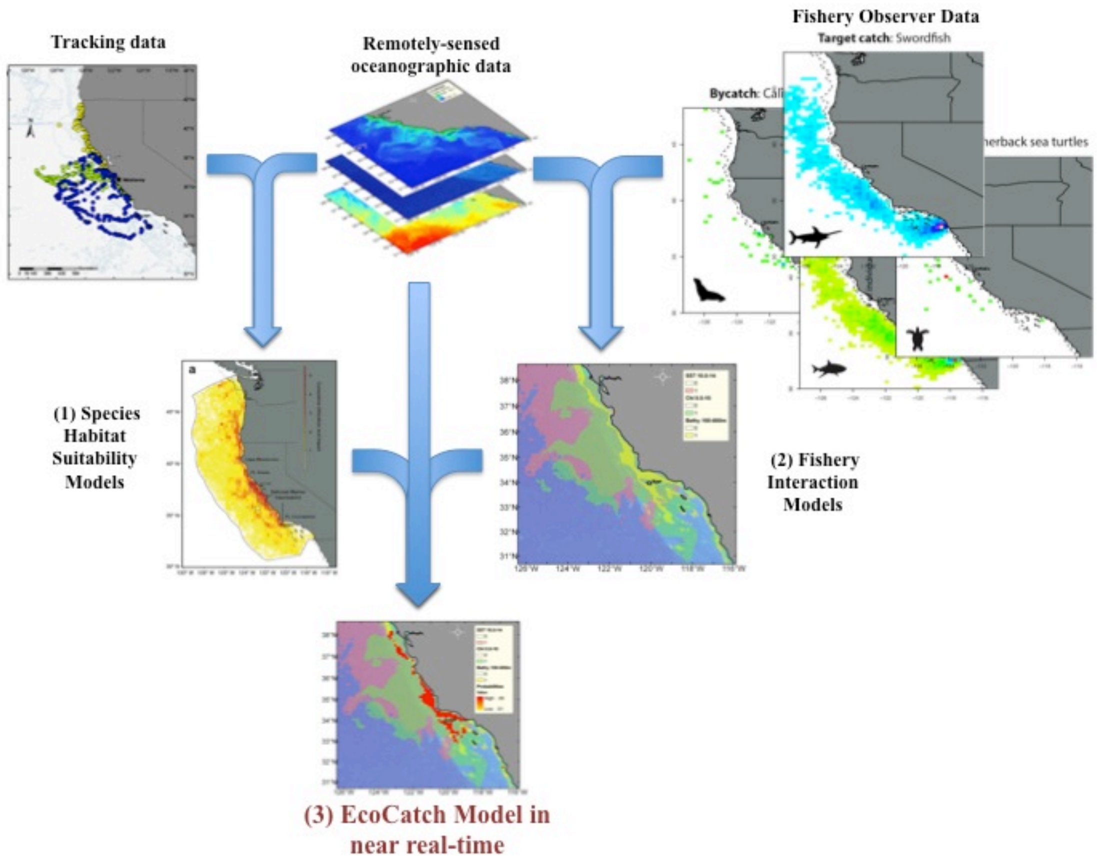


Figure 3. Workflow. The EcoCatch model will be a near real-time model that integrates catch and bycatch probability across multiple species.

(1) Suitable Habitat Modeling: In this step, we will aim to determine the large-scale habitat of our focal species, and further refine this habitat based on foraging locations; this will be done using fishery-independent data (satellite tracking and/or survey data). We will use spatial modeling techniques to determine if species are associated with the specific environmental variables listed above (see Earth Observations). These techniques will include generalized additive models, maximum entropy models and/or ensemble models (Redfern et al. 2006, Araujo and New 2007, Hazen et al. 2012). Predictive habitat models such as these have been shown to be effective for predicting habitat across a number of different taxa, and have proven effective for management issues such as reduction of fisheries bycatch (Howell et al. 2008, Block et al. 2011, Zydelis et al. 2011, Hazen et al. 2012).

We have extensive tracking data for each of the three bycatch species (between 18 and 144 tracks per species; Table 1). All of the satellite tracks have been previously modeled using a switching state-space model (SSSM; blue sharks: (Block et al. 2011); California sea lions: (Breed et al. 2011); leatherbacks: (Benson et al. 2011, Bailey et al. 2012)) to account for location error and to determine the behavioral state (‘transiting’ or ‘foraging’) of the animals (Jonsen et al. 2005, Bailey et al. 2008, Bailey et al. 2010, Maxwell et al. 2011). To create models of suitable habitat within the DGN fishing area, we will combine the tracks with remotely-sensed oceanographic data likely to influence animal habitat preference, such as sea surface temperature, eddy kinetic energy, primary productivity and frontal persistency (see Earth Observations above; (Zydelis et al. 2011)).

Following techniques applied in WhaleWatch, our suitable habitat modeling technique will be two-fold. First, we will identify overall suitable habitat. Second, we will use behavioral states estimated from the SSSM to determine where foraging areas are likely to occur. The first model (overall suitable habitat) will use presence-absence of animals to identify where animals are likely to occur. We will simulate absences using 'pseudo-absences' generated from correlated random walk models (Aarts et al. 2008). Pseudo-absences will be compared to presence data from satellite tracking data to determine habitat preferences within the area of the current and historical DGN fishery. In the second model, we will identify foraging habitat preferences by predicting where foraging is likely to occur, based on the two SSSM behavioral modes. 'Foraging' behavior is indicated by where animals spend increased time in an area, in contrast to 'transiting' behavior, which is indicative of high speeds and persistent directed movement as the animal moves rapidly through a region. By refining habitat preference using probable foraging habitat, we are able to determine not just where animals may be found but also how likely they are to spend an increased amount of time in a region, and thereby which areas are likely to have a higher probability of interaction with fishing gear. For each of the models, some data will be withheld for model cross-validation.

(2) Fishery Interaction Modeling: In Step 2, we will capture the spatial extent of the fishery by constructing models similar to above by using fishery-dependent data. From this we will create density surfaces that characterize the occurrence and abundance of catch or bycatch based on their association with specific environmental variables through time. Using spatial modeling techniques similar to those above (GAMs, etc.), we will use observer data and remotely-sensed oceanographic data to determine if catch of swordfish and bycatch of species is associated with specific environmental variables. Using the NOAA DGN fishery observer database, we will determine catch per unit effort (CPUE) of swordfish and bycatch per unit effort (BPUE) for each bycatch species. We will determine the overall fishery interaction 'habitat' based on presence or absence of a species catch within sets of fished areas, and relationships between presence and remotely-sensed oceanographic variables such as SST, primary productivity, etc. Second, we will use CPUE or BPUE to determine if, within fishery interaction habitat, higher levels of catch or bycatch are associated with specific environmental factors derived from remotely-sensed oceanographic data. Again, for each of the models, some data will be withheld for model cross-validation.

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 while maintaining catch within different regions. This will allow managers to effectively consider trade-offs between increasing catch and/or reducing bycatch of focal species and determine the optimum scenarios.

(3) Model Integration: The EcoCatch Model: Finally, we will integrate the two models above to determine where animals are likely to be found (habitat suitability) and where they are likely to be caught (fishery interaction); from the integrated model we can predict bycatch and catch in near-real time scenarios. For the focal bycatch species, we will create a bycatch probability model by integrating the habitat suitability model and the bycatch model together following Zydelis et al. (2011). For each bycatch species i, we will create an algorithm that determines the probability of bycatch (P_i) 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 suitability of species *i,* and B_i is the predicted fishery interaction of species *i*. We will create a matrix of bycatch probabilities for each species using the models developed above.

For both catch and bycatch species, we will create thresholds of high or low catch/bycatch, based on regulations, receiver operating characteristics (ROC) or other metrics as deemed appropriate (Guisan and Zimmermann 2000). From this we will combine the catch and bycatch species layers to create the EcoCatch model. Using the EcoCatch model we can determine, for example:

- The overall probability of bycatch (P_b) by summing bycatch probabilities 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.

Temporal scale of the final near real-time outputs will be determined, according to such variables as temporal resolution of remotely-sensed oceanographic data, satellite tag data range, fishing effort information, and how the model fits with management objectives.

Fishermen as 'Crowdsourcers'

While the Pacific Fishery Management Council and NMFS Southwest Regional Office are the primary regulatory end-users, fishermen themselves are the true end-users, as they will be applying the tool in practice. We have a strong and growing network of fishermen collaborators who have stated their willingness to serve as 'crowdsourcers', i.e., collect data and validate the models as they develop. We provide a letter of support from several of these fishermen. Fishermen will collect data similar to the observer data but specific to our focal species. These data include date, time and location of sets, soak time (the primary metric for effort in this fishery, along with net length) and the number of study bycatch species caught in each set. These valuable *in situ* observations can be fed into models as primary input data or for model validation. Additionally, by involving fishermen in data collection, it increases their investment in the project and the likelihood that they will use the tool, even prior to its formal integration into management. Further, based on their feedback throughout the project we will be able to better refine the tool to make sure it is relevant, accessible and effective.

Proposition addressed in the Feasibility Study Project, and sustainability of EcoCatch

Above we have outlined the full scope of work for EcoCatch. Within the first year of the project (Feasibility Study Project) we aim to:

(1) **Determine end-user needs.** We will work with the NMFS Southwest Regional Office and fishermen to identify the specific needs and applications they anticipate for EcoCatch. This process is already underway, and is being conducted through regular email, phone and in-person meetings at relevant offices and fishing wharfs.

(2) **Develop individual models.** We will develop the two overarching models that will go into EcoCatch: (1) habitat suitability models from tracking data of bycatch species and remotely-sensed oceanographic data and (2) fishery interaction models from fishery observer data of bycatch and catch species and remotely-sensed oceanographic data. In the feasibility phase, we will be working to determine predictor variables for habitat distribution and remotely-sensed environmental data, and creating preliminary models for each species individually.

(3) **Develop a beta EcoCatch model.** Using the individual species models above, we will develop a beta EcoCatch model, giving a preliminary view of what the integrated EcoCatch model will look like, and how it could be applied to improve fishery management.

In the Decision Support phase that follows the Feasibility Study phase, we will:

(1) Work with the NMFS Southwest Regional Office and fishermen to modify and refine the EcoCatch model based on feedback we recorded from demonstrations of the beta EcoCatch model.

(2) Work with our partner fishermen to test the model on-the-water by comparing catch and bycatch rates with model predictions.

(3) Increase the sophistication of the economic component of the model by integrating data on metrics that fishermen deem as critical such as catch value, distance from port, fuel cost, etc.

(4) Present the model at relevant Southwest Regional Office and Council meetings in order to gain additional feedback, and give demonstrations of the model's application using currently debated management scenarios for the drift gillnet fishery

(5) Transition the EcoCatch model to be hosted on the Southwest Regional Office website, ensuring that the model can be updated automatically using freely available remotely-sensed data.

Estimate of the Application Readiness Level

We estimate that at the start of the Feasibility Study Project, our project is at ARL 1 (Basic Research), as our goal is to work closely with fishermen and the NOAA/NMFS Southwest Regional Office to determine how our research results can most effectively enhance decision-making. This discussion will then form the basis for our analysis in which we will formulate the components of the system (ARL 2 Application Concept), the initial development of the tool EcoCatch, and its application to the decision-making activity (fishery management). By the end of the one year Feasibility Study, we anticipate having reached ARL 3 (Proof of Application Concept), as we will have tested and validated the tool (EcoCatch), detailed the needs of the decision making process through our partnerships with end-users (fishery managers and fishermen) and made a convincing case for EcoCatch's application to fishery management.

In the Decision Support stages of Years 2 and 3, we anticipate moving from ARL 3 to ARL 8 (Functionally Proven). If the Feasibility Study indicates EcoCatch to be as beneficial to fisheries management as we anticipate, our aim is demonstrate its use by illustrating scenarios in which it can improve catch for fishermen and reduce bycatch of protected species for managers. We would transition the final EcoCatch tool to the NOAA/NMFS Southwest Regional Office early in Year 3 with in-person demonstrations and a manual on its use. This would allow managers to provide feedback on the usability and features of the tool so any final modifications can be made before the project is completed. The aim is that the tool would automatically update its predictions based on the latest remotely sensed environmental data allowing EcoCatch to be sustained beyond the duration of the project on the NOAA website. Through our fishermen partners, we anticipate that they will begin to use the tool voluntarily (ARL 8) as soon as we are able to show its utility in reducing bycatch (the goal of the Decision Support stage).

Challenges and risks affecting project success

We do not anticipate significant issues or delays in the project, as all of the data have been collected and we have a strong team with prior experience in all of the project components. Each member is committed to providing data, time and input into the project. All members of our team have worked together in various configurations previously and already communicate regularly. For this project, communication will be facilitated by email and conference phone calls. Additionally, the team is geographically located in two primary locations, the Monterey Bay Area and the San Diego Area, further facilitating regular in-person meetings to discuss project progress.

Potential challenges and risks that may, however, affect project success are:

Lack of telemetry or observer data to determine meaningful relationships between focal species and environmental variables.

- Preliminary data exploration suggests that our focal species will show strong associations with environmental data. Studies have shown that California sea lions have strong associations with bathymetry and sea surface temperature (Kuhn and Costa 2006, Weise et al. 2006, Weise et al. 2010), leatherback sea turtles with a number of variables including SST, eddy kinetic energy, and chlorophyll (Benson et al. 2011, Bailey et al. 2012) and blue sharks with sea surface temperature, bathymetry and productivity fronts (Queiroz et al. 2010, Stevens et al. 2010, Queiroz et al. 2012). Swordfish are also widely known to be associated with SSTs, particularly fronts, chlorophyll (as a proxy for light at depth) and oxygen (Seki et al. 2002, Santos et al. 2006, Dewar et al. 2011, Abecassis et al. 2012). Further, fishermen have determined similar preferences over many years fishing, particularly for blue sharks and swordfish (DGN fishermen, personal communication). They have used knowledge of these preferences to increase target catches of swordfish and decrease bycatch of blue sharks, but they are particularly interested in being able to better refine their understanding of where bycatch is likely to occur.

Models cannot provide spatial resolution to be of use to managers and/or fishermen on-the-water.

- While this may be the case in some regions, we are confident that our models will provide a level of spatial resolution that will allow managers to make decisions about spatial management of the fishing area. Remote-sensing data in the region is some of the highest quality and resolution in the world (see Earth Observations), thereby allowing for ability to make predictions at a comparable spatial scale. Furthermore, as indicated above, fishermen regularly make decisions on a fine scale (< 10 km) about where good places to catch target species occur and where to avoid bycatch species. Thus, we are confident that the resolution of our models will be sufficient to increase fishing efficiency and improve management decision-making.

All profitable catch areas intersect with high bycatch areas.

- While this may occur during some limited time periods, we have explored the observer database and our initial investigations show that a large percentage of high catch sets are coincident with low levels of bycatch. Further, fishers know that while some overlap in environmental habitat does occur between swordfish and bycatch species, this is not uniformly true. One of the primary goals of EcoCatch is to understand not just where and when high catch/low bycatch areas occur, but also to characterize the environmental forces that drive these areas so that more sustainable fishing practices and spatial designations can be developed.

Feasibility Criteria

Feasibility of our project will be assessed and measured by:

1. Ability to create dynamic catch/bycatch probability models for all four focal species (three bycatch, one target catch) using available data and easily accessible remotely sensed data.
   Feasibility Metric:
   - Collect all data. ***Completed:*** *All data have been collected.*
   - Each team member is committed to providing data, time, and input into the project.
   - Each team member brings strong experience with each of the data types and models to be applied (*e.g.,* Bailey et al. 2008, Bailey et al. 2010, Bailey et al. 2012, Block et al. 2011, Dewar et al. 2011, Hazen et al. 2012, Maxwell et al. 2011, Maxwell et al. 2012, Zydelis et al. 2011).
2. Ability to successfully integrate the models together to create EcoCatch and to give a realistic large-scale picture of the catch-bycatch landscape.
   Feasibility Metric:
   - Team members have extensive experience integrating large datasets for management applications (*e.g.,* Bailey et al. 2008, Bailey et al. 2010, Bailey et al. 2012, Block et al. 2011, Dewar et al. 2011, Hazen et al. 2012, Maxwell et al. 2011, Maxwell et al. 2012, Zydelis et al. 2011).
   - All members of the team have worked together in various capacities, and currently communicate regularly.
3. The successful collection of *in situ* data by drift gillnet fishermen. Their participation in the program is key to both validating models and to their long-term use of the resulting EcoCatch model.
   Feasibility Metric:
   - Participating fishermen have already been contacted and have agreed to collaborate (see Support Letters).
4. Input from the Pacific Fishery Management Council, NOAA/NMFS Southwest Regional Office and drift gillnet fishermen to evaluate the utility and feasibility of applying EcoCatch to reduce bycatch on-the water and as a decision making tool for the Council.
   Feasibility Metric:
   - The NOAA/NMFS Southwest Regional Office is an active partner in this project (see Support Letter), and while the Council is not able to provide support letters for projects, they have expressed interest in seeing this work go forward and have requested to be kept apprised of its progress.
   - Members of our team (S. Kohin, H. Dewar) are actively involved in the Council process and, in addition to our Southwest Regional Office partners, will act as liaisons to the Council to ensure feasibility in management.
   - We have an active and growing network of fishermen (see Support Letters) with whom we have already established relationships. We will continue to work with them to establish tool feasibility.

Anticipated Results/Improvements

In making regulations regarding the DGN fishery, the Council and the NOAA/NMFS Southwest Regional Office are currently forced to consider coarse, often single-species data. For example, in designating the Leatherback Conservation Area (which encompasses 596,000 km^2 of historical fishing grounds; Figure 1), the closure was designed by drawing a box around the 23 highly-dispersed observed leatherback interactions without the ability to consider why interactions occurred where they did, or where interactions are likely to occur in the future. Additionally, they were unable to consider whether this closure would increase bycatch of other species due to shifted fishing effort, nor were they able to explicitly consider the effects of the closure on fishermens' livelihoods. These missing considerations are not a result of the Council or Southwest Regional Office's lack of desire to explicitly consider these components; rather, they lack the ability to consider all of these pieces holistically.

EcoCatch will fulfill this urgent need by providing real-time habitat and bycatch/catch probability of both key bycatch species and the primary target species. This will allow users the ability to simultaneously consider the some of the ecological and economic impacts of fishing and the trade-offs associated with fishing. For example, if fishermen shift fishing effort from one region to another to avoid bycatch of one species – either by choice or due to a regulatory mandate – they will know if the transfer of effort is likely to result in a higher probability of another bycatch species. For managers, EcoCatch will also allow them the ability to predict economic impacts on fishermen by being able to compare the probability of catching swordfish across potential closed area scenarios. Specific deliverables anticipated from this project include:

1. Suitable habitat models for the focal bycatch species (leatherback sea turtles, California sea lions, blue sharks) that identify environmental habitat characteristics across the range of the California Current.
2. Fishery interaction models for the three focal bycatch species and the primary catch species (swordfish) that determine environmental characteristics associated with high bycatch or catch of each species within the fishery's current and historic range.
3. A beta Eco-Catch model consisting of near real-time bycatch and catch probability models that combine our understanding of where species are likely to be found (suitable habitat models) with what makes them most likely to be caught or bycaught (observer models). These models can be used on-the-water by fishermen and in making management decisions at the Pacific Fishery Management Council level.
4. Regular presentations at Council and NMFS Southwest Regional Office meetings, and presentations at national level scientific meetings.
5. Manuscript describing this innovative modeling approach.

The aim of this project is to improve decision making both (1) at the Pacific Fishery Management Council level and (2) at the level of individual fishermen. EcoCatch will provide the Council with the ability to quantitatively, spatially, empirically and transparently understand the impact of management decisions across multiple bycatch species and on fishermen's livelihoods. By working directly with the Council and NOAA's Southwest Regional Office throughout the process, we are confident that this tool will be used within the management structure. Additionally, drift gillnet fishermen have shown a keen interest in participating in this project and in the outcomes of EcoCatch, as indicated by their Letter of Support. As a result of the personal relationships our team has developed with fishermen, we will be able ensure that the products also meet their needs on-the-water, and that it will be utilized by them on a regular basis.

Project Management

Partnership Agreements: NOAA, SDSU, and UMCES/CBL have previously worked together on several analyses including of tracking data, which resulted in a number of recent publications (Bailey et al., 2009, Block et al. 2011, Maxwell et al. in review, Hazen et al. 2012). We therefore do not anticipate any significant problems in data sharing between the institutions. All outputs from this project (code, data, models) will be made available to all project investigators for use in future projects. NOAA has experience hosting decision-support tools to reduce anthropogenic impacts on marine species.

Management Approach: The project management approach is one of collaboration. We will maintain contact via email and phone, and through three EcoCatch Working Group Meetings. This working group is already funded by Stanford University's Center for Ocean Solutions and will allow for team members to meet three times in Monterey, CA during the year-long project. Additionally, the working group provides funding for additional individuals with expertise beyond our team to attend the working group meetings (up to 17 individuals/meeting); thus, we will include our end-user partners (fishermen and the NMFS Southwest Regional Office) in the working group, along with other individuals who have expertise in similar projects (e.g., Evan Howell, lead developer for TurtleWatch).

Expected Contribution, Roles and Responsibilities of Team Members: We have assembled a diverse team where individuals will have unique roles and responsibilities. Drs. Lewison, Costa, Dewar, Kohin, Eguchi, and Benson are responsible for contributing tracking and fishery observer data, and Dr. Maxwell is responsible for compiling these data; this step has already been completed. Drs. Foley, Fossette, Bograd and Hazen will be integral for obtaining remotely-sensed data and serving the initial beta EcoCatch model on the NOAA/SWFSC website. Drs. Lewison, Bograd, Bailey, Hazen, Costa, Crowder, Dewar, Kohin, Eguchi, and Benson are responsible for providing feedback on the ecological and management relevance of models as they are developed. As postdoctoral researchers on the project, Drs. Maxwell, Wingfield and Fossette will be primarily responsible for developing and validating models, with additional assistance from Drs. Hazen and Bailey given their broad expertise in habitat model development. Responsibilities of team members in relationship to individual tasks are detailed in the table below.