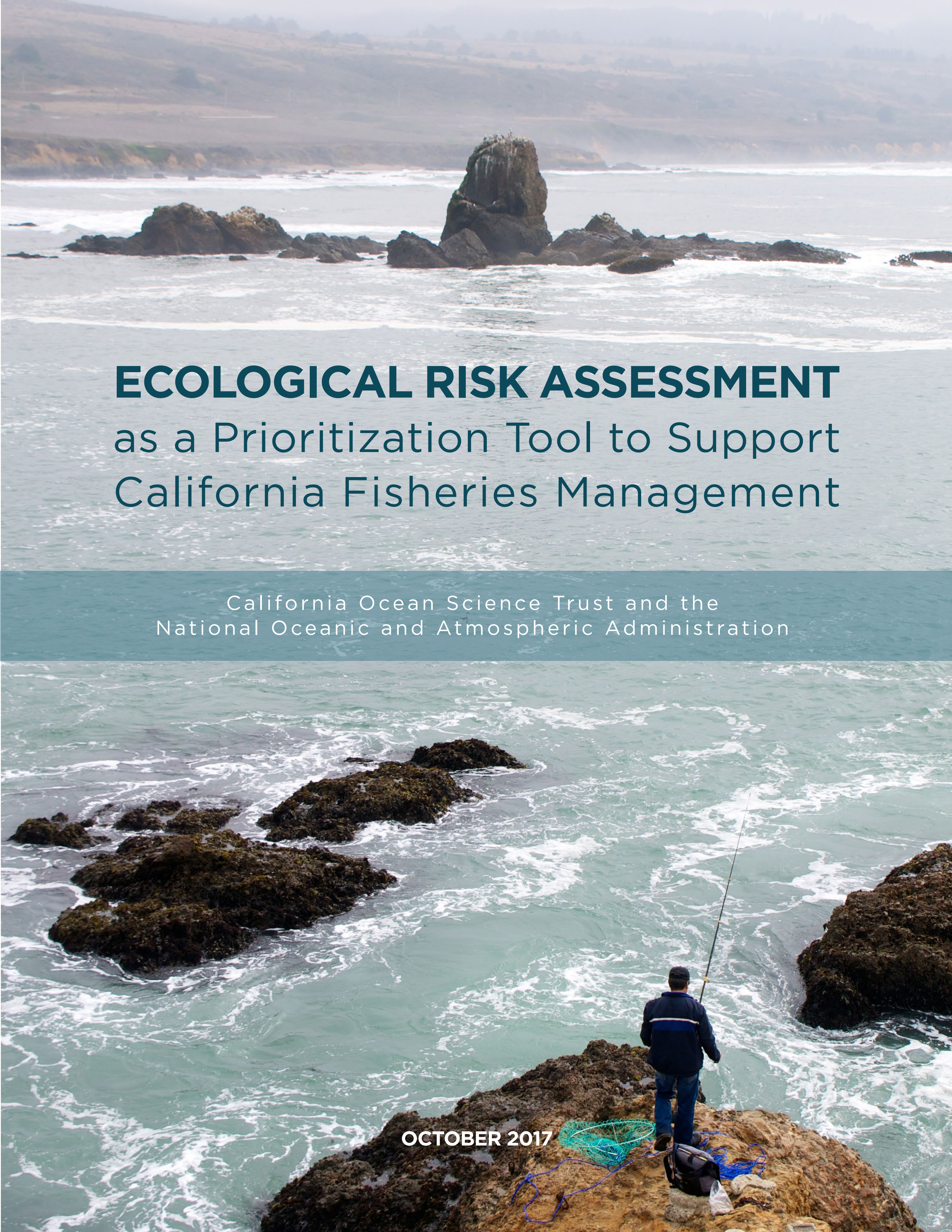

ECOLOGICAL RISK ASSESSMENT

as a Prioritization Tool to Support California Fisheries Management

California Ocean Science Trust and the
National Oceanic and Atmospheric Administration

OCTOBER 2017

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California Ocean Science Trust

Ocean Science Trust (OST) is an independent, non-profit organization that brings together governments, scientists, and citizens to build trust and understanding in ocean and coastal science issues. We empower participation in the decisions that are shaping the future of our oceans. We were established by the California Ocean Resources Stewardship Act to support managers and policymakers with sound science. For more information, visit our website at www.oceansciencetrust.org.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) is an agency that enriches life through science. Our reach goes from the surface of the sun to the depths of the ocean floor as we work to keep citizens informed of the changing environment around them. From daily weather forecasts, severe storm warnings, and climate monitoring to fisheries management, coastal restoration and supporting marine commerce, NOAA's products and services support economic vitality and affect more than one-third of America's gross domestic product. NOAA's dedicated scientists use cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers and other decision makers with reliable information they need when they need it.

Project Team

The project team included California Ocean Science Trust, the California Department of Fish and Wildlife (CDFW), NOAA Fisheries, and the California Ocean Protection Council (OPC).

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Acronyms

CDFW - California Department of Fish and Wildlife

ERA - ecological risk assessment

ERAF - ecological risk assessment for fishing

ERAEF - ecological risk assessment for the effects of fishing

FMP - fishery management plan

GIS - geographic information system

MPAs - marine protected areas

MLMA - Marine Life Management Act

NGO - non-governmental organization

NOAA - National Oceanic and Atmospheric Administration

OPC - California Ocean Protection Council

OST - California Ocean Science Trust

OPC-SAT - Ocean Protection Council Science Advisory Team

PSA - productivity suceptibility analysis


Image credit: Dennis Jarvis

About the Report

Management Context

The Marine Life Management Act (MLMA) was established in 1999 to ensure the conservation, restoration, and sustainable use of California's marine living resources. The California Department of Fish and Wildlife (CDFW) developed a Master Plan for Fishery Management Plans (Master Plan), which was adopted by the Fish and Game Commission in 2001, to help achieve the objectives of the MLMA and focus management effort on the highest priority species. Through 2018, CDFW and its partners are amending the Master Plan to consider advancements in our understanding of the status of California's marine resources, as well as tools and approaches in the field of fisheries science and ocean management. An important focus of the amendment is to develop a more systematic, efficient, and transparent approach to prioritizing species for management action that reflects the needs, risks, and value of fisheries, as well as CDFW's priorities and capacity.

Project Overview

This project to research, pilot, and test ecological risk assessments (ERAs) was initiated by CDFW to inform the development of a comprehensive, ecosystem-based approach to fisheries prioritization for management action. CDFW fishery experts, including staff responsible for overseeing the management of specific fisheries, were directly involved in all aspects of this project, including developing, refining, and testing the ERA tools. CDFW fishery experts were also involved in stakeholder workshops to examine the ERA tools and solicit feedback for further revision and improvements.

The project was funded by the California Ocean Protection Council (OPC), with additional support from the Resources Legacy Fund. The primary goal was to develop a method to assess the potential risk to selected fisheries from fishing. This method is intended for consideration by CDFW as part of the process to amend the MLMA Master Plan. This report has been provided to CDFW and may be integrated, in full or in part, into a draft Master Plan Amendment. Additional information about the Master Plan amendment process, including key resources and opportunities for stakeholder engagement, is available at http://www.wildlife.ca.gov/Conservation/Marine/Master-Plan.

This report and other supporting materials can be found on the OST project page at: http://www.oceansciencetrust.org/projects/era/.

Image credit: Dennis Jarvis

Highlights and Key Findings

- A new ERA, tailored for California's fisheries management, provides a tool that managers, fisheries scientists, and other stakeholders can use to understand the relative potential risk posed by fishing activities to target species, bycatch species, and marine and estuarine habitats.
- The new ERA can be applied in both data poor and data rich contexts, and allows an evaluation of the individual and cumulative risks posed to multiple components of the ecosystem simultaneously, giving breadth to its potential application.
- Based upon an existing application that was customized to align with the mandates and priorities of CDFW, the process to pilot an ERA for selected California fisheries demonstrates the efficiency of drawing from an existing method and offers a tool that can be used directly by others or customized further to meet localized needs.
- An inclusive and transparent process has set the stage for broad buy-in and adoption. Co-development of the ERA by scientists and CDFW fishery experts, and with stakeholder input during two in-person workshops, fostered inclusion of multiple perspectives and interpretations of existing data and information.
- This process delivers a scientifically rigorous tool with broad utility. The tool can underpin scientific prioritization of the development of management actions and screen for potential impacts of fishing activity on an ecosystem.

Executive Summary

The California Department of Fish and Wildlife (CDFW), with funding from the Ocean Protection Council, requested that California Ocean Science Trust (OST) research, develop and pilot-test a risk-based decision framework that advances the goals of the Marine Life Management Act (MLMA) with regard to prioritization of fisheries for management attention, and is transparent, cost-effective to implement, and scientifically rigorous. CDFW sought an ecosystem-based management tool that could assess three ecosystem components: target species, bycatch species, and marine habitats. CDFW was also interested in considering the potential benefits of California's network of marine protected areas (MPAs). The goal of this project was to provide CDFW with a scientifically-vetted pilot test of an Ecological Risk Assessment (ERA) that could inform the prioritization among fisheries as part of the MLMA Master Plan amendment process.

ERAs can be valuable quantitative tools to help focus limited fishery management resources on species that are most at potential risk from fishing activities and other stressors. In general, ERA results are not mandates for management action, but serve to identify fisheries with potentially greater risk. Once a set of fisheries has been scored, fisheries with potentially higher risk should be further examined by users of the tool, usually fishery managers, to 1) better understand why they have been scored higher risk and, 2) use that information to decide if further assessment is required and/or a management action is needed.

Building off previous research, OST worked with experts from NOAA Fisheries West Coast Region and MRAG Americas to test two different risk assessment tools, an ERA (adapted from Samhouri and Levin, 2012) and a NOAA Productivity and Susceptibility Analysis (PSA), respectively. This project was one of thirteen MLMA Master Plan amendment information gathering projects intended to inform the State's process to amend the MLMA Master Plan for Fisheries.

Customization and development of the pilot ERA tool was iterative between the members of the project team (CDFW, OST, NOAA, OPC), and towards the end of the pilot, with stakeholders including fishermen, environmental NGOs, and other federal fisheries experts. The bycatch and habitat components were requested by CDFW. The target component, which is similar to PSA, was added by NOAA and OST to demonstrate the functionality of a single ERA tool and a customized approach tailored to California. Because California has a widespread and abundant MPA network, we also considered the potential benefits from MPAs to each ecosystem component (i.e., target, bycatch, habitat).

In order to customize and test the pilot ERA tool, we selected nine fisheries that would allow us to apply the tool on a wide range of different fishery characteristics. A fishery was defined as a combination of a species, a fishing gear, and a sector (sport or commercial). The following nine fisheries were chosen from the list of 45 fisheries for which a PSA was conducted:

- **White Sturgeon** - Hook and line, sport
- **Kelp Bass** - Hook and line, sport
- **California Halibut** - Hook and line, sport
- **California Halibut** - Trawl, commercial
- **California Halibut** - Gill net, commercial
- **California Halibut** - Hook and line, commercial
- **Pacific Herring** - Gill net, commercial
- **Spiny Lobster** - Hoop net, sport
- **Spiny Lobster** - Trap, commercial

All ERAs create results by asking experts to "score" various attributes that may contribute to a species' or habitat potential risk to an identified stressor, in this case fishing activity. Sensitivity attributes are the expected response of a target species, bycatch guild, or habitat given that it is exposed to a stressor. Exposure attributes are those that represent the potential for a stressor to influence a target species, bycatch guild, or habitat based on attributes that include spatial, temporal, and management factors. In this report they are sometimes referred to as the "sensitivity axis" or "exposure axis."

In this pilot ERA, fishery experts were asked to complete scoring on a spreadsheet to be used to create results to help us refine the pilot ERA tool. The final spreadsheet has been evaluated by CDFW with feedback from stakeholders. The spreadsheet is unique due to the highly collaborative and iterative nature of the process used to create it, its customization for California State fisheries, and they way in which it incorporated multiple types of knowledge (e.g., academic, fishery experts, applied managers, fishermen). The spreadsheet represents a bridge between traditional risk assessments, often created by scientists in isolation, and managers who need a tool that meets their specific needs and the needs of stakeholders.

The scores provided on the spreadsheet were analyzed, summarized, and presented in this report to help readers understand the tool, its application, and how fisheries could be prioritized if the pilot ERA is used in the future. Results do not indicate a mandate for management action. Rather, they indicate a potential risk that should be examined further by users of the tool to determine whether and if a management action is needed.

Target ERA - What is the potential relative risk posed to target species from fishing activity?

The target ERA has many similarities to the NOAA PSA. The main difference between this ERA and other risk assessment approaches, including PSA, is that it was designed for California's fisheries with data that are readily available to managers and with explicit consideration of California's MPA network (and is replicated for the bycatch and habitat ERAs). For each fishery in the target ERA, scores were added and averaged (i.e., arithmetic average method) independently for sensitivity and exposure attributes. Of the nine fisheries assessed, relative risk to target species was greatest for white sturgeon in the sport hook-and-line fishery, followed by the four California halibut fisheries. For all five of these fisheries, relatively high risk scores resulted from relatively high scores for nearly all exposure attributes as opposed to sensitivity attributes. Low sensitivity attribute scores for these target species implies that high exposure levels are not expected to jeopardize their persistence.

Bycatch ERA - What is the potential relative risk posed to bycatch from fishing activity?

The approach taken to risk assessment for species caught as bycatch in the fisheries allows for users to score risk to a representative species within a guild (a group of related species). For prioritization, the goal is to understand if there is a potential risk and then later work to understand the species and other details of that potential risk once a fishery has been prioritized. For the purposes of the ERA pilot project and workshops, bycatch was defined as "catch that is returned to the water."

In the analysis of each fishery in the bycatch ERA, the attribute scores for each guild (e.g., elasmobranchs, salmonids) are summed and averaged by axis, and those guilds with no interaction with a fishery were removed from analysis. In contrast to the Target ERA scoring, fisheries with multiple bycatch guilds had the score from each guild summed (i.e., cumulative method). Two of the bycatch ERA attributes were weighted to represent 50% of the total score among all attributes within each axis to reflect their relative importance. One of these weighted attributes related to sensitivity attribute (release mortality) and the other related to exposure (magnitude).

The rank ordering of relative cumulative risk to bycatch guilds differed from that of risk to target species. Specifically, the California halibut commercial gill net and trawl fisheries posed the greatest relative cumulative risk. This result emerged because both fisheries interact with six of the ten bycatch guilds, the greatest number among the nine fisheries.

Habitat ERA - What is the potential relative risk posed to habitat from fishing activity?

The approach to the habitat component follows a similar structure to that of bycatch. One main difference between the bycatch and habitat ERA components is that for fisheries that occur in multiple habitats, users are also asked to estimate the percent of fishing activity that takes place in each habitat (sum = 100%) for use in subsequent analysis.

In the analysis of each fishery in the habitat ERA that has multiple guilds (e.g., kelp, soft bottom) scores are summed and averaged by axis, and those guilds no interaction with the fishery are removed from analysis. The arithmetic average method was used to calculate final scores but was weighted by the percentage of fishing that occurs among impacted habitats. Similar to the bycatch ERA, two habitat ERA attributes also were weighted to reflect their relative importance. One exposure attribute (gear footprint) and one sensitivity attribute (potential damage to habitat from fishing gear) were weighted to represent 50% of the total score for all attributes. This decision was made based on the recognition that it is the gear itself which has the greatest potential impact on the habitat among all attribute factors.

Relative potential risk to habitats was greatest for the California halibut commercial trawl fishery, which affects nearshore soft bottom and habitat-forming marine invertebrates. While these two habitats were both highly exposed, neither was expected to be particularly sensitive. Compared with the risk assessment for bycatch guilds, the remaining eight fisheries did not show as much variation in risk score for habitats.

Data Quality

As part of this pilot, data quality was scored for every attribute and a written rationale for the attribute was provided. Data quality was not integrated into any final results because time and effort were focused on finalizing results for the three ecosystem components. However, this information is available in the appendices and could be used to refine future ERAs and - as suggested at the workshops - to identify knowledge gaps related to the nine fisheries.

Next Steps and Conclusions

Going forward, it is within the purview of CDFW or other potential users to consider whether and if this pilot ERA meets their needs. This pilot test involved many key decisions. Several others remain should CDFW choose to implement the ERA in whole or in part. These include:

- Key decision points for tool refinement and implementation such as how to treat data quality, and whether and how to identify actions and associated costs of lowering risk
- Key decision points for PSA vs. ERA for target fisheries
- Key decision points for stakeholder engagement
- Consideration of the use of regional ERAs

The process we used to create the pilot ERA was scientifically rigorous, efficient, highly iterative and collaborative among NOAA, OST, and CDFW, and incorporated stakeholder input. The result is a tool that, if implemented, can minimize capacity issues and can largely be conducted by CDFW. Additionally, should CDFW decide to implement the tool, the five CDFW fishery experts who helped to pilot the tool are now in-house experts.

CDFW can now assess whether and if the tool meets current management needs to prioritize fisheries based on the three ecosystem components - target, bycatch, and habitat. Finally, the process we used demonstrated a way for CDFW to select an existing ERA for customization to meet their specific management goals and ecosystem features. This pilot ERA and process can be utilized by others to meet similar goals or to select and customize their own ERA efficiently.

1. Introduction

Image credit: Ed Bierman

1.1 Overview

CDFW requested that OST research, develop, and pilot test a risk-based decision framework that advances the goals of the MLMA with regard to prioritization of fisheries for management attention, and is transparent, cost-effective to implement, and scientifically rigorous. CDFW sought an ecosystem-based management tool that could assess three ecosystem components: target species, bycatch species, and marine and estuarine habitats. CDFW was also interested in considering the potential benefits of California's network of MPAs. The goal of this project was to provide CDFW with a scientifically-vetted pilot test of an ERA that could inform the prioritization among fisheries as part of the MLMA Master Plan amendment process.

REQUEST FROM CDFW

Develop risk-based tool(s) to consider:

- Potential risk of fishing activity to ***target species***
- Potential risk of a fishery's operation to ***bycatch species***
- Potential risk of a fishery's operation to ***habitats***
- Consider implications of California's network of ***marine protected areas (MPAs)*** to the target, bycatch, and habitat ecosystem components

1.2 Why Risk Assessment?

ERAs can be valuable quantitative tools to help focus limited fishery management resources on species that are most at risk from fishing activities and other stressors. ERAs for fishery management are frameworks for assessing the likelihood that a fishery, species, or ecosystem component faces significant negative impacts from anthropogenic or natural sources (e.g., fishing activities, impaired water quality, climate change, ocean acidification). ERAs are one of the few readily-available tools to help a manager move away from single species management and towards ecosystem based management (Link et al., 2002; FAO 2003). California began exploring the use of ERAs for state marine fishery management in 2013 through a series of OPC Science Advisory Team (OPC-SAT) meetings and several exploratory projects (see "Timeline of Events" on the following page).

Timeline of Events

Exploring Ecological Risk Assessments for California

September 4, 2013

Ocean Protection Council Science Advisory Team workshop: "Advancing Science in California Fisheries"

California began exploring the use of ERAs for state marine fisheries management in 2013 at an OPC-SAT meeting "Advancing Science in California Fisheries." The OPC-SAT came together with fishery decision makers to discuss the best ways for scientists to partner with CDFW to support sustainable fisheries management. (OST 2013)

July 29, 2015

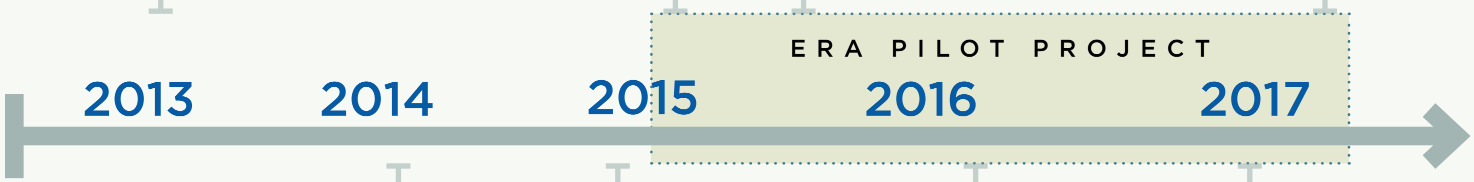
Ocean Protection Council provides funding to support development of ERA tools for CDFW

OPC funded OST to partner with CDFW to customize, test, and pilot an ERA, and apply a PSA to specific fisheries. (OPC 2015)

2016 - 2017

Pilot ERA Development

OST worked with NOAA Fisheries and CDFW to explore risk to habitats and bycatch species by adapting an existing ERA framework for California state marine fisheries.



September 2014

"Ecological Risk Assessments: A Roadmap for California Fisheries"

OST led the development of a report that examined multiple ERA frameworks for understanding fishery vulnerabilities to various stressors, including fishing pressure and climate change. This project identified lessons learned from existing applications, and considerations for adopting such methods for California fisheries. (OST 2014)

December 2016

PSA Applied to 45 California Fisheries

OST contracted with MRAG Americas to conduct a NOAA PSA on 45 target fisheries (i.e., gear/sector/species combinations), representing 36 California state-managed species. (MRAG Americas 2016)

June/July 2017

ERA Stakeholder Workshops

OST hosted two stakeholder workshops to review the ERA draft tool and scoring for nine pilot fisheries.

February 25, 2015

Ocean Protection Council Science Advisory Team workshop: "Readying California Fisheries for Climate Change"

The "roadmap" report supported a second OPC-SAT meeting in 2015 where members of the scientific community were once again brought together with CDFW managers to discuss how the scientific community could aid the State in the development of the MLMA Master Plan amendment. (OST 2015)

There are many types of ERAs. The term refers to a class of risk assessment frameworks, which in turn can address either absolute or relative risk (Box 1), along with a range of goals. The particular framework chosen, adapted as needed, and implemented depends on the management situation it is designed to support, but most contain elements that are considered key components (Box 2). It is important to create or adapt an ERA for clearly defined applications and management goals. ERAs that are built for different projects will therefore have different components and inputs, carefully chosen and designed to address the specific management goals (e.g., maintain stock under fishing, minimize bycatch impacts). ERAs can support different types of managers' information needs, which, in turn, inform different types of management decisions.

ERAs can assess both data-poor and data-rich fisheries on the same scale. They each take uncertainty in the data or expert's knowledge into account with approaches that vary among tools. In addition to prioritization, ERAs can also expose data gaps or identify specific concerns in a fishery to guide future management decisions.

In general, ERA results are not mandates for management action, but serve to identify fisheries of potential concern for one or more ecosystem components. Once a set of fisheries has been scored, fisheries with potential higher risk should be further examined by users of the tool, usually fishery managers, to

1. better understand why they have been scored higher risk, and,
2. use that information to decide if a management action is needed.

ERAs err on the side of caution and are designed to produce false positives (a fishery that is deemed high risk by the tool, but in reality is not at true risk) instead of false negatives (a fishery that actually has high risk for a negative outcome, but instead was scored as low risk by the ERA). There are many reasons why a fishery may score a false positive, and further investigation or interpretation of the results is needed to address these situations. Risk assessments can flag potential issues and allow stakeholders to work together with managers to understand and potentially avoid negative outcomes. For example, a fishery scored as higher potential risk may have recently developed a fishery management plan (FMP), so the State may consider the risk to be addressed (e.g. California spiny lobster). Conversely, if a fishery is falsely estimated to have lower risk, it could undergo a stock decline or some other avoidable outcome while managers are focused on other priorities.

BOX 1. KEY DEFINITIONS

Absolute Risk - the chance that a species, habitat, or ecosystem feature will experience potential decline on an absolute scale ranging from impossible to certain. Calculation of absolute risk scores requires validation and more time-consuming and data-intensive methodologies than relative risk calculations.

Relative Risk - the chance that a species, habitat, or ecosystem feature will experience potential decline or degradation due to a particular activity, in terms of higher or lower exposure and sensitivity scores, without reference to an absolute scale that defines the probability associated with these scores.

(Adapted from Samhouri and Levin, 2012)

BOX 2. Key Pillars of an ERA tool and process

There are tradeoffs with each of these key pillars, and there is no one "right" ERA or approach. However, these are the key criteria to keep in mind when developing or customizing and ERA.

- **Comprehensive**
    - Can assess multiple or single stressors (e.g., fishing activity, habitat degradation, climate change)
- **Flexible**
    - Can assess data poor alongside data rich fisheries
    - Can assess among or within fisheries (usually not both)
    - Applicable to all types of fisheries, irrespective of size, fishing method, species, etc.
- **Synthesizes knowledge**
    - Brings different types of expertise (e.g., managers, NGOs, academic scientists, fishermen, etc.) together to share knowledge
- **Transparent and repeatable**
    - Clear process, methods, data, and assumptions used in analyses
    - Understandable to different users (e.g., managers, stakeholders, scientists)
    - Clear methods for how results will be used by managers
- **Cost effective**
    - Existing knowledge, information, and data within realistic limits of time and resources
- **Scientifically defensible**
    - Undergoes independent peer review
- **Useful for management**
    - Inform risk management responses and decisions
- **Takes a precautionary approach to uncertainty**

(Adapted from Hobday et al. 2011)

2. Ecological Risk Assessment Approach

Image credit: NOAA Fisheries West Coast

Building off previous research, OST worked with experts from NOAA Fisheries Science Centers and MRAG Americas to test two different risk assessment tools, a NOAA PSA and an adapted ERA (modeled after Samhouri and Levin, 2012), respectively. This project was one of thirteen MLMA Master Plan amendment information gathering projects[1] intended to inform the State's process to amend the MLMA Master Plan for Fisheries[2]. The goal of the project is to help CDFW prioritize fisheries for management consideration (e.g., the development of enhanced status reports, or enhanced status reports with rulemaking, or FMPs). By piloting two ERA methods alongside each other with varying levels of State fishery expert and stakeholder involvement, we provide CDFW with options to consider for future implementation.

Based on the request from CDFW, OST was tasked with implementing two different risk assessment approaches:

1. **Approach 1: Apply an existing ERA** - Conduct an established risk assessment on a large number of fisheries to assess risk to target species. The project team selected the NOAA productivity susceptibility analysis (PSA) to be conducted on 45 California marine fisheries.
2. **Approach 2: Customize an ERA for California** - Customize an ERA that can assess fishing risk to target, bycatch, and habitats that takes into account California's unique environment and assets (e.g., MPAs). The project team selected the Samhouri and Levin (2012) ERA tool to adapt for California and pilot on nine fisheries.

For each approach, a fishery was defined as a fishing gear, sector (i.e., commercial or sport), and species combination (Box 3). We also call this unique fishery combination a "unit of analysis." This approach allows for differences between sport and commercial fisheries and among different gear types to be assessed separately; however, the overall risk score can be assessed at the species level, which is the way that the State currently manages many of its fisheries. For example, in both of these information gathering risk assessment projects, spiny lobster was

BOX 3. KEY DEFINITION

Fishery - for the purposes of the ERA pilot, a fishery is defined as a unique gear type, sector (e.g., commercial or sport), and species combination. This is also known as a "unit of analysis."

[1] For more information on the MLMA Master Plan projects, visit https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=132845&inline

[2] For more information on the MLMA Master Plan Amendment process, visit https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=132745&inline

analyzed separately for the sport and commercial sectors to allow managers and stakeholders to understand the relative risk that each fishery poses to spiny lobster and associated bycatch and habitats independently. This approach also allows managers to combine the scores of each fishery to understand potential overall risk to spiny lobster, bycatch, and habitats at the target species level (i.e., all gear types and sectors combined into a single score).

2.1 Why These Two Risk Assessment Approaches?

2.1.1 Approach 1: Apply an Existing ERA (NOAA PSA)

PSA is a widely used risk assessment tool in fisheries management for assessing the vulnerability of a fishery species or stock, using a set of predetermined measurable attributes and score rankings. It was one of the tools used to prioritize management of fisheries in the previous 2001 CDFW Master Plan for Fisheries. PSA has evolved over time from its initial creation and has been adapted and applied across the globe.

Briefly, PSA assumes that the overall vulnerability of a fished species to impacts from fishing depends on two characteristics:

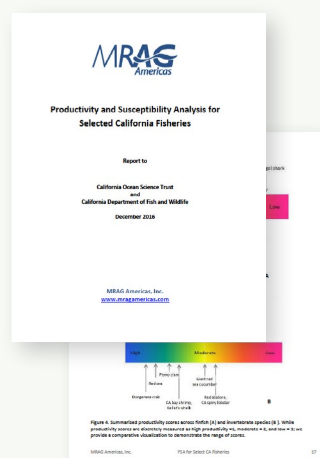
1. **the *productivity* of a species/stock** based on life history traits that determine whether a fished species could sustain or recover from fishery-related impacts.
2. **the *susceptibility* of the species/stock** to impacts from fishery-specific activities.

Productivity and susceptibility attributes of each stock are examined and scored. There are several different PSA methods, which vary slightly in their attributes and scoring methods, though most methods provide similar results.

See Box 4 for an overview of the 2016 PSA conducted by MRAG Americas on behalf of CDFW.

BOX 4. PRODUCTIVITY AND SUSCEPTIBILITY ANALYSIS FOR SELECTED CALIFORNIA FISHERIES (MRAG AMERICAS, 2016)

In 2016, a NOAA PSA was conducted on 45 units of analysis as part of an information gathering process related to California's MLMA Master Plan Amendment. The NOAA PSA methodology was selected for its inclusion of attributes that evaluate the management strategy and value of a fishery, along with its ability to generate and consider a data quality score. The analyses were conducted by MRAG Americas, Inc. with input and review from CDFW experts. The list of fisheries for analysis represents a diversity of stocks that span commercial and sport sectors, gear types, coastal areas, and include finfishes and invertebrates. It also represents those state-managed fisheries with the highest commercial landings, recreational catch, or commercial/recreational participation, as evaluated by CDFW.



More information on the methods, interpretations, and results can be found in the PSA report online here.

2.1.2 Approach 2: Customize an ERA for California (Samhouri and Levin, 2012)

Selecting an ERA

There are a large number of existing ERAs and other fishery risk assessment tools utilized across the globe. OST's first step was to whittle down this vast body of tools into several for consideration for customization by the project team. Based upon our previous work, conversations and recommendations from ERA experts, and the scope of what the ERA tool needed to do, we narrowed our field of ERAs to the following:

- **Ecological Risk Assessment for Fisheries (ERAF) -** developed for Canadian fisheries (Martone et al. 2012)
- **CARE and CARE lite tool** - developed by Environmental Defense Fund (Battista et al. 2017)
- **Ecological Risk Assessment for the Effects of Fishing (ERAEF)** - developed for Australian fisheries (Hobday et al. 2011)
- **Multiple Stressor Ecosystem-based Risk Assessment** - developed as part of the NOAA integrated ecosystem assessment toolkit (Samhouri and Levin, 2012)
- **Qualitative Consequence Risk Assessment Analysis** - developed for Australian fisheries (Fletcher 2005)
- **Cumulative impacts assessment** - a quantitative assessment for assessing multiple human impacts (Stelzenmüller et al. 2010, Halpern et al. 2009)

When selecting an ERA for customization we considered many aspects of scientific rigor, capacity, efficiency, and the ability to meet CDFW's needs. Some of the key considerations were if the tool in its current state or, if easily adapted, could:

- Be applied at a state-wide scale while accommodating regional fisheries
- Be implemented efficiently
- Be scientifically rigorous (already independently peer-reviewed)
- Have previous real-world applications
- Accommodate fisheries as California defines them (i.e., single species level)
- Address habitat, bycatch, and target species risk in the same tool, on the same scale
- Consider California's assets and management structures (e.g., MPA network)
- Address stressors other than fishing activity
- Be customizable in time frame allotted
- Be utilized by CDFW with minimal outside expertise or support at the end of the pilot

The team ultimately chose to work with and customize the Samhouri and Levin (2012) methodology (Figure 1). The decision was primarily driven by the established scientific rigor of the tool, its ability to address fisheries at the species level rapidly, and its ability to be customized both to address bycatch and habitat but also to take into account California's MPAs.

Figure 1. Overview of the pilot ERA process steps based on Samhouri and Levin (2012).

3. Ecological Risk Assessment Pilot

Image credit: Oregon Department of Fish and Wildlife

The pilot ERA, adapted from Samhouri and Levin (2012), was designed to ask the following question:

"What is the relative risk posed to a target species, bycatch species, or habitat from the prosecution of the fishery?"

CDFW was interested in exploring potential risk posed to two ecosystem components based on their mandates in MLMA legislation: limiting bycatch and habitat conservation. Through conversations with CDFW, risk assessment experts from academia, NOAA, and some of the foremost risk assessment experts in Australia, OST proposed expanding the pilot to include target species and the ability to take into account our network of MPAs (which were not in place during the creation of the previous Master Plan).

3.1 Methods

3.1.1 Customizing the ERA for California Fisheries

The Samhouri and Levin (2012) methodology was originally created to conduct an assessment that considered the overall health of an ecosystem due to multiple stressors (e.g., fishing activity, coastal development, agriculture). The tool did and continues to draw from ERAEF and PSA. The project team worked with the tool's creator to adapt it to specifically address one stressor (fishing activity) on target species, bycatch species, and habitat. The bycatch and habitat components were requested by CDFW. The target component, which is similar to PSA, was added by NOAA and OST to demonstrate the functionality of a single ERA tool and demonstrate a customized approach tailored to California.

Because California has a widespread and abundant MPA network, we also considered how MPAs interact with each ecosystem component (i.e., target, bycatch, habitat). The California MPA network was established from 2007 to 2012, primarily to protect representative portions of ecosystems and those fished species which would benefit from this protection. This network has ecological benefits to exploited species and their ecosystems by protecting the diversity and abundance of marine communities and ecosystems from environmental and anthropogenic stressors. For each of the three ERA ecosystem components, an MPA attribute was created that explicitly reduces their exposure fishing by taking into account the California MPA network (see Appendix B for attribute definitions for each component).

Each selected fishery receives an overall score for target, bycatch, and habitat based on Sensitivity and Exposure scoring attributes (Box 5). See Appendix B for a spreadsheet with complete attributes and definitions for sensitivity and exposure attributes for the pilot ERA.

BOX 5. KEY DEFINITIONS

Attribute - A factor or criterion which contributes to the overall risk to a target species, bycatch guild, or habitat in which the fishery occurs.

Sensitivity - The expected response of a target species, bycatch guild, or habitat given that it is exposed to a stressor. Attributes include resistance and recovery factors. It is sometimes referred to as the "Sensitivity Axis."

Exposure - The potential for a stressor to influence a target species, bycatch guild, or habitat based on attributes that include spatial, temporal and management factors. It is sometimes referred to as the "Exposure Axis."

Fishery Selection for the Pilot

In order to customize and test the pilot ERA tool, we selected nine fisheries that would allow us to apply the tool on a wide range of different fishery characteristics. We selected from the list of 45 fisheries used for the PSA in order to facilitate easy comparisons between tools. Within that list we sought to find a mix of fisheries for which we could compare and test performance of the tool based on the following comparisons and considerations:

- Invertebrate and vertebrate species
- Nearshore and pelagic species
- Recreational and commercial sectors within a fishery and fisheries with only one sector
- Different gear types
- Varying economic value and/or cultural or regional value
- Habitat or species that are considered ecosystem feature representatives
- High trophic level species and forage species
- Geographic considerations: statewide and regional; northern, central, and southern California
- Data rich and data poor
- Fisheries with and without FMPs

Based on these factors, the following nine fisheries (or "units of analysis") were chosen (Figure 2):

- **White Sturgeon** - Hook and line, sport
- **Kelp Bass** - Hook and line, sport
- **California Halibut** - Hook and line, sport
- **California Halibut** - Trawl, commercial
- **California Halibut** - Gill net, commercial
- **California Halibut** - Hook and line, commercial
- **Pacific Herring** - Gill net, commercial
- **Spiny Lobster** - Hoop net, sport
- **Spiny Lobster** - Trap, commercial

These fisheries were not previously prioritized. They were selected to help the team customize and refine the pilot ERA tool, based on stakeholder input, and to help us understand how and if the tool is working to meet its management goals and underpinning scientific rigor.

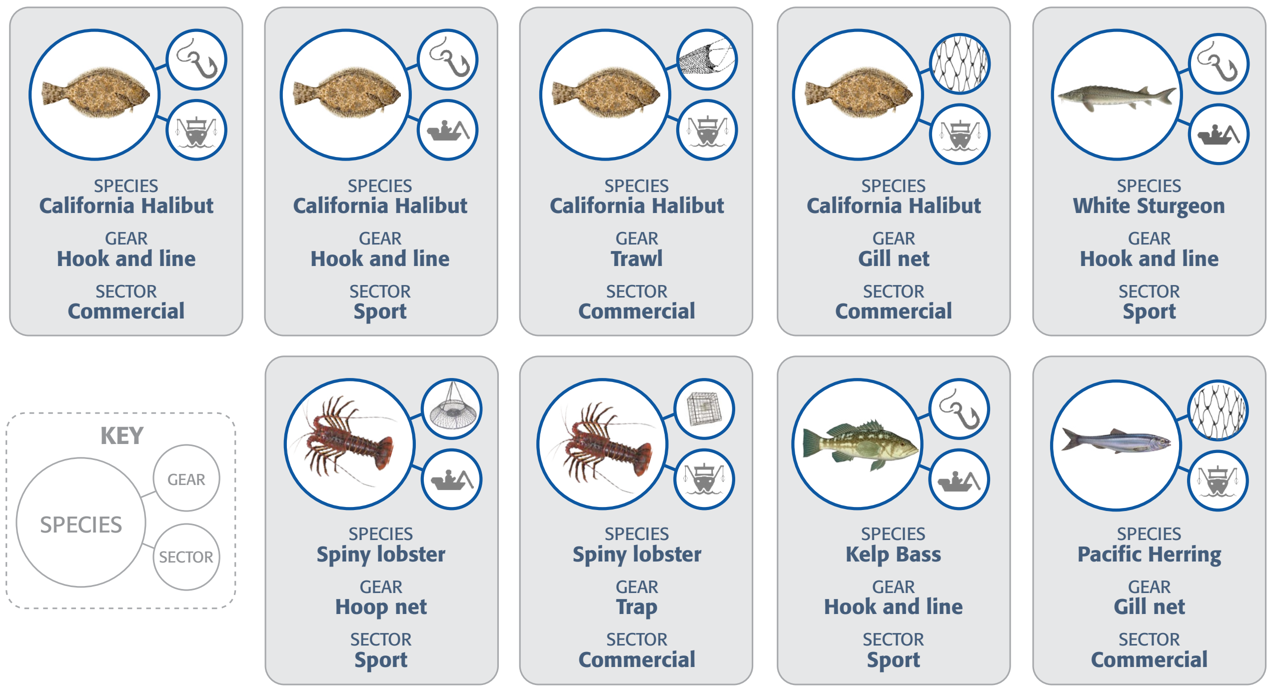


Figure 2. Nine fisheries or "units of analysis" (representing a species, gear type, sector combination) selected for the pilot ERA analysis.

Target Species Analysis: What is the potential relative risk posed to target species from fishing activity?

We revisited the original Samhouri and Levin (2012), PSA (Hobday et al., 2011; Patrick et al., 2010), and other risk assessment methodologies to select, customize, and define attributes to be scored as part of this pilot ERA. The main difference between this ERA and other risk assessment approaches, including PSA, is that it was designed for California's fisheries with data that are readily available to managers and with explicit consideration of California's MPA network. It also has fewer attributes than the NOAA PSA.

Bycatch Analysis: What is the potential relative risk posed to bycatch from fishing activity?

For this component, the main challenge was to find a way to assess risk to bycatch species without having to do an assessment on every species caught in a fishery. For prioritization, the goal is to understand if there is a potential risk and then later work to understand the species and other details of that potential risk once a fishery has been prioritized. In order to create this ERA component, NOAA and OST reviewed other methodologies (Samhouri and Levin 2012; Zhou et al., 2008; Fletcher et al., 2005, Hobday et al., 2011). The approach taken allows for users to score risk to bycatch for a representative species within a guild (a group of related species). Potential benefits from California MPAs were also a factor that was considered in the creation of this component by creating an explicit MPA attribute; this was scored relative to potential benefit rather than potential risk.

Definition of Bycatch for Piloting ERA

There are multiple definitions of bycatch at both the state and federal level, but this does not change the mechanics of the tool itself. Rather, it is more important to have a definition be consistently applied within the bycatch ERA tool application.

For the purposes of the ERA pilot project and workshops, bycatch was defined as “catch that is returned to the water” (Box 6), with the following additional guidance:

BOX 6. KEY DEFINITION

Bycatch - for the purposes of the ERA pilot, the project team defined bycatch as catch which is returned to the water.

- For seven of the 10 guilds, a bycatch guild is scored if there is “significant” bycatch (greater than 1% of the catch of the target species by either weight or number) for any species within that guild. We use the most frequently caught species within that guild and score it as appropriate. If all species within the guild have what we consider to be non-significant bycatch, we do not score that guild.
- For the other three guilds (marine mammals, marine birds, and threatened and endangered species and/or overfished rockfish), if there is ***any*** bycatch of these guilds, we score the most common species within the guild.
- Sub- and supra-legals of the target species are scored as bycatch.

Defining Bycatch Guilds

Ten guilds were initially suggested by CDFW to contain the full spectrum of species possible as bycatch in California’s marine fisheries, but to limit the number of guilds so that scoring was not an unreasonable task. The guilds were refined by the project team and stakeholders during workshops.

Bycatch guilds were as follows (Figure 3a):

- **Marine mammals**
- **Marine birds**
- **Threatened or endangered species, and/or overfished rockfish**
- **Elasmobranchs**
- **Salmonids**
- **Flatfish**
- **Other rockfish**
- **Pelagic finfish**
- **Non-pelagic finfish**
- **Marine invertebrates**

Habitat Analysis: What is the potential relative risk posed to habitat from fishing activity?

The approach to the habitat component follows a similar structure to that of bycatch. When a fishery is being scored, the user is asked to only score the habitat types in which the fishery operates. In order to create this ERA component, NOAA and OST reviewed other methodologies (Williams et al., 2011; Arkema et al., 2014) to propose options to the project team for their input and feedback. One main difference between the bycatch and habitat ERA components is that for fisheries that occur in multiple habitats, users are also asked to estimate the percent of fishing activity that takes place in each habitat (sum = 100%) for use in subsequent analysis. California MPAs were also a factor that was considered in the creation of this component by creating an explicit MPA attribute; this was scored relative to potential benefit rather than potential risk.

Defining Habitat Groups

Ten habitat groups were selected based on knowledge of California coastal and oceanic ecosystems, management definitions of habitat utilized by CDFW, and availability of GIS mapping data, using the smallest number of groups feasible for efficiency (Figure 3b). One of the options for this component in the future would be for some of the attributes to be scored using GIS spatial analysis rather than expert scores. For example, spatial overlap with MPAs could be automated to analyze percent cover of total habitat inside MPAs and outside MPAs in state waters.

Habitat types included:

- **Habitat-forming marine vegetation**
- **Habitat-forming marine invertebrates**
- **EstuariesNearshore hard bottom (0-200m)**
- **Nearshore soft bottom (0-200m)**
- **Offshore hard bottom (>200m)**
- **Offshore soft bottom (>200m)**
- **Pelagic**
- **Hard bottom intertidal**
- **Soft bottom intertidal**

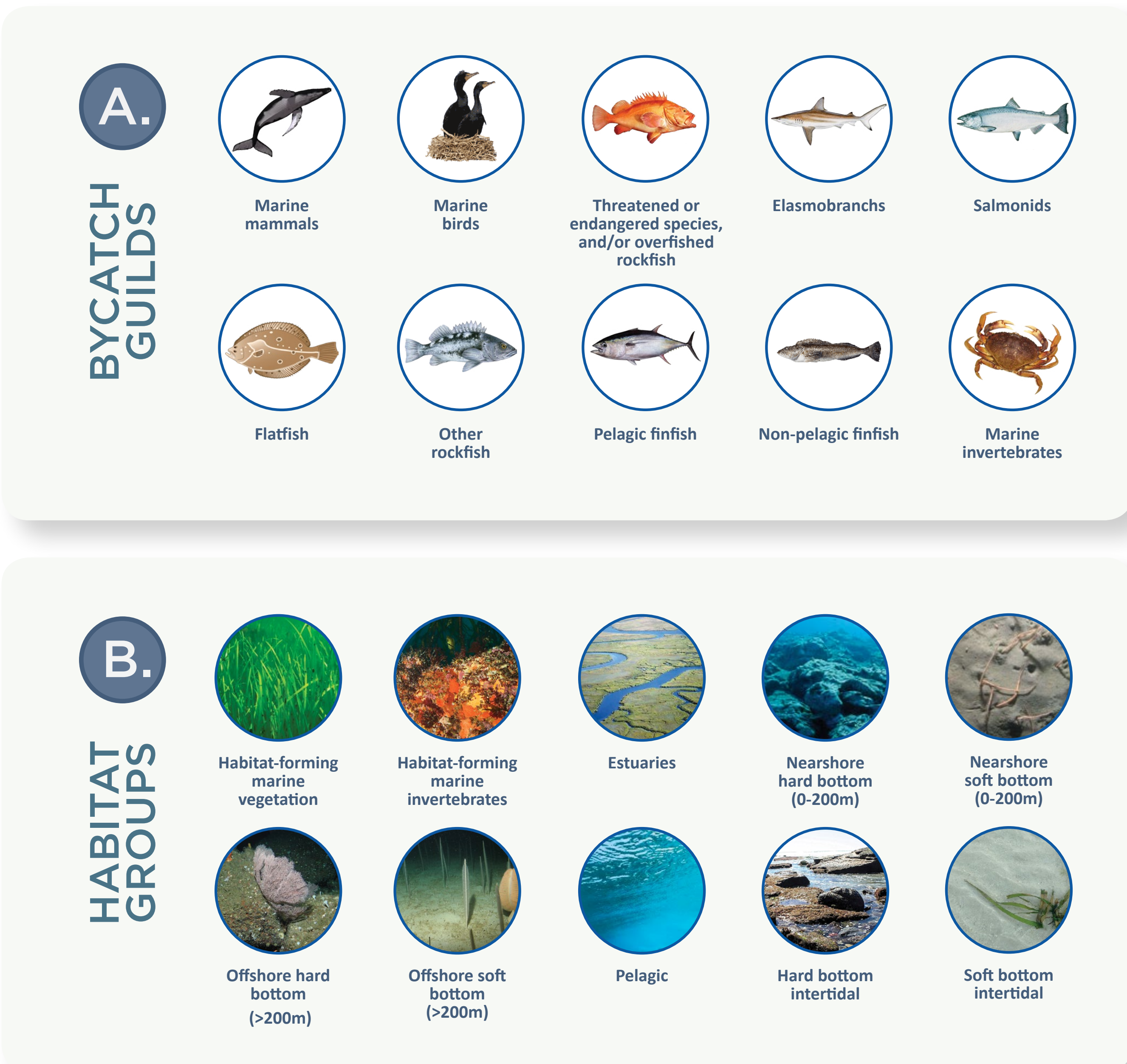


Figure 3. (A.) Bycatch guilds and (B.) habitat groups included in the pilot ERA analysis.

Photo credits: Marine Applied Research and Exploration; other creative commons.

Creating a Process and Structure for Scoring the ERA

Customization and development of the pilot ERA was iterative among the project team, and with stakeholders including fishermen, environmental NGOs, and other federal fisheries experts. NOAA and OST worked to develop options for an approach to scoring and analysis to present to the project team. Once an approach was chosen, NOAA and OST began development of a scorable spreadsheet. Development of the spreadsheet was highly collaborative and iterative, initially involving multiple rounds of review by CDFW and suggested changes, followed by CDFW experts testing the spreadsheet by scoring the nine fisheries.

Prior to the stakeholder workshops, CDFW experts completed at least two rounds of scoring and the project team made changes to the spreadsheet after each scoring exercise based on feedback from CDFW. The project team made further changes after receiving input from each of the two stakeholder workshops and the CDFW fishery experts rescored the spreadsheets after each workshop. The spreadsheet and results in this report represent the final iteration of the pilot ERA tool that resulted from this process. CDFW may decide to pursue further changes and refinements should they decide to use the pilot ERA in the future.

Finalizing the Scoring Spreadsheets

The final draft spreadsheet is included in Appendix B along with scored spreadsheets and scoring instructions. Many changes were made during its development based upon: 1) knowledge of users and stakeholders, 2) data that most users could access and apply, and 3) knowledge of how California fisheries and fishermen operate. At first glance, the scoring bin descriptions and cut-offs may seem arbitrary. However, the project team made efforts to base them in science, when possible, and then refine them utilizing knowledge about management in California and data available. This approach helped to clarify, standardize, and quantify the different score bin descriptors to decrease the likelihood of users scoring or interpreting attributes differently.

The final draft spreadsheet has been tested by CDFW with some feedback from stakeholders. The spreadsheet is unique due to the highly collaborative and iterative nature of the process used to create it, its customization for California State fisheries, and they way in which it incorporated multiple types of knowledge (e.g., academic, fishery experts, applied managers, fishermen).. The spreadsheet represents a bridge between traditional risk assessments, often created by scientists in isolation, and managers who need a tool that meets their specific needs.

In creating the final draft spreadsheet the team had several goals in mind:

- Continue to ensure strong scientific grounding and rigor.
- Create a spreadsheet that is easily understood by multiple types of users and stakeholders.
- Since multiple users may complete the scoring, efforts were made to reduce subjectivity in attribute descriptions and scoring bins. For example, we moved away from descriptions like "reduce impacts somewhat" to concrete or quantitative examples of reduced impacts as part of the definition and scoring bin descriptors.
- Select a reasonable number of attributes for each ERA component to create an efficient scoring process for the user as well as final scores that vary among Units of Analysis. (Azose and Samhouri, unpublished manuscript; Samhouri and Levin (2012) sensitivity analysis in supplemental material; Hobday et al. 2007). Additionally, studies have shown that the number of attributes affects the "sensitivity" of the attributes themselves. With too few attributes, each attribute affects the overall score disproportionately. With too many attributes, none of them change the score enough, possibly resulting in similar overall scores that could hamper efforts by managers to make decisions.

Selecting a Scale

The project team decided to extend the scale of risk scores from a range of 1-3 (which is the scale used in the NOAA PSA) to range of 1-4 (where 1 represents the lowest potential risk and 4 represents the highest). This decision was made for two key reasons: 1) to create a broader range and potentially greater differences in results among fisheries and 2) to create a scoring system where there is no half-way, or middle score (i.e. on a scale of 1-3, 2 is the exact middle, on a scale of 1-4, users are forced to pick a score on either side of the middle). This second reason draws upon previous risk assessment literature and lessons learned (Morrison et al., 2015; OST 2014) and ensures the user will select a score either above or below the middle mark. We also instructed users to score every attribute.

Selecting Attributes

The final draft spreadsheet represents the current decisions made by the project team with input from stakeholders. Table 1 shows the attributes for target, bycatch, and habitat. See Appendix B for a full spreadsheet, which includes each attribute, attribute definitions, and the scoring bin descriptions for each attribute. However, other attributes were considered over the course of the pilot and there are still others that were never considered but are represented in other fisheries risk assessment tools across the globe. In the future, CDFW or other users of the tool may choose to incorporate these attributes, change definitions, or change scoring bin descriptions. Table 2 provides examples of changes or rationale for excluding original attributes (and their definitions).

Data Quality Scoring and Rationale

Accounting for the quality of the data used to score attributes is a key component of any modern ERA. Because ERAs ask a user to generate scores for fisheries that are both data poor and data rich, the data used can range from expert opinion to formal stock assessments. Because it is important to understand how the attributes were scored, experts are asked to provide a rationale about why they chose a particular score. An expert can explain if the score was based on peer-reviewed literature, landings data, personal observation, or some other source. The rationale used in scoring is very important for interpreting results, for ensuring standardization in scoring rationale among experts, and for transparency with stakeholders. Because of the above, the experts are asked to assign each attribute score an additional data quality score (Table 3). The data quality scores were adapted from the Monterey Bay National Marine Sanctuary application of the Samhouri and Levin (2012) methodology.

Testing the Scoresheet and Generating Draft Results for Tool Refinement

For this pilot, one CDFW fishery expert was responsible for scoring each of the five chosen species, and completed the scoring for each fishery multiple times. One of the fishery experts, the CDFW project lead, worked with the other fishery experts to review scores to ensure that all experts were scoring the attributes consistently. Some of the CDFW fishery experts reached out to fishermen to assist in the scoring process. The process allowed for us refine the spreadsheet and to standardize the scoring rationale among attributes.

Additionally, we received feedback on the spreadsheet from participants at the stakeholder workshops. This helped us to further understand each fishery and resulted in more spreadsheet and scoring changes. While this process was beneficial for developing and piloting the tool itself, it is not necessarily the process for future use. This is discussed further in ***Section 4: Next Steps***.

Analyzing Scores

Approach to Assessment of the Three Ecosystem Components: Target, Bycatch, and Habitat

Multiple approaches for methodology and analysis were explored as part of this pilot. Efforts were made to not choose methodologies that 'fit' our preconceived notions of the results. When making choices the project team relied on peer-reviewed scientific literature to draw from tested methodologies, ruling out methodologies that produced results that were highly unreasonable, and accepting methodologies even if they produced surprising, but still believable results. Additionally, at times the project team saw certain decisions as being more policy-driven than science-driven. For example, in some management contexts it might make sense to weight certain bycatch guilds higher than others.

Table 1. Exposure and sensitivity attributes for the three ecosystem components of the ERA.

	Target	Bycatch	Habitat
Exposure attributes	• Current landing trends and management strategy • MPA coverage and/or other permanent spatial closure (MPAs, RCAs, etc.) • Gear Selectivity • Spatial intensity • Temporal intensity • Value of exploited species	• Management effectiveness • MPA coverage and/or permanent spatial closures (RCA, gear closures) • Current status • Spatial intensity • Temporal intensity • Magnitude	• Management effectiveness • MPA coverage and/or permanent spatial closures (RCA, gear closures) • Spatial overlap • Temporal (# months /yr) and other fishery closures • Gear footprint
Sensitivity Attributes	• Age at maturity • Behavioral response • Fecundity • Breeding strategy • Fishing mortality	• Age at maturity • Behavioral response • Fecundity • Release mortality	• Current status • Recovery time • Population connectivity • Potential damage to habitat from fishing gear

Table 2. Examples of changed or deleted attributes from Pilot ERA Scoresheet.

Original Attribute	Original Attribute Description	Change or Rationale for excluding
Management effectiveness and current stock status	The track record of current management approaches used to mitigate impacts of fishing activity, taking into account stock status when known	For target ERA, changed to "current landing trends and management strategy" to reflect both data and metrics used by CA fishery managers and to make the attribute score bin descriptions more concrete and less subjective. Similar changes that mirror this decision were made to the bycatch and habitat ERAs as well.
Life Stage	Life stage(s) affected by a stressor; if stressor affects individuals before they have the opportunity to reproduce, recovery is likely to be inhibited	This attribute was removed from both the target ERA and the bycatch ERA. Although, this attribute has precedence in other ERAs there was not strong support from stakeholders or from State managers for its inclusion. The scientists on the team did not think the overall ERA approach or score ERA was weakened by its removal.
Intensity	The intensity of the fishing pressure (amount of catch) in the area where a habitat is known to occur	This was removed from the habitat ERA due to concern and feedback from the first stakeholder workshop that it was duplicative of spatial intensity. There should be consideration given in the future to whether this attribute should be added or combined with spatial intensity, especially if a GIS analysis component is pursued.

Table 3. Data quality scoring descriptions.

Score	Description	Example
1	Very limited data. Information based on expert opinion surveys or on general literature reviews from a wide range of habitats or species.	No empirical literature exists to justify scoring for a focal habitat or species in relation to a particular activity/pressure but reasonable inference can be made by the person conducting the risk assessment.
2	Limited data. Estimates with high variation and limited confidence, or based on studies of similar habitats/species or of the focal habitat/species in other regions.	Scoring based on a study of a similar habitat or species outside of the study region.
3	Adequate data. Information is based on limited spatial or temporal coverage, moderately strong or indirect statistical relationships, or for some other reason is deemed not sufficiently reliable to be designated as "best data"	Use of presence-absence data from ad hoc sampling efforts; use of relatively old information; etc.
4	Best data. Substantial information exists to support the score and is based on data collected for the habitat or species in the study region.	Data-rich assessment of habitat or species status, with reference to historical extent and current trends.

For the purposes of this pilot study, we defined a fishery (or "unit of analysis") as each unique target/gear/sector combination, similar to the PSA approach. The pilot ERA produces a relative risk score for impacts to target, bycatch, and habitat separately. When multiple units of analysis exist for a target species, they can be averaged to produce an overall target-specific score. For example, California halibut was scored as four separate fisheries, to produce four separate scores, but can also be averaged to create one score for the species across all fisheries. All results were analyzed using customized code to be utilized in an open source application, "R."

Complementary analyses were conducted to enable the presentation of different options for consideration by scientists and fisheries managers at CDFW. For all analyses, possible scores for each attribute ranged from 1-4. This approach varies slightly from that used for the PSA, which ranged from 1-3 and did not specifically define a non-interaction score.

Target ERA Analysis

For each target unit of analysis in the target ERA, scores were added and averaged (i.e., arithmetic average method) independently for Sensitivity and Exposure attributes. For a fished species with multiple units of analysis (e.g. California halibut), exposure and sensitivity results were further averaged to provide an overall target-specific score.

Bycatch ERA Analysis

Each unit of analysis in the bycatch ERA that has multiple guilds (e.g., elasmobranchs, salmonids) had scores for each guild summed and averaged by axis. Average values from each guild were further summed ("cumulative method") to provide final scores for each target or unit of analysis. The arithmetic average method (as described above for target analysis) does not incorporate sample size (i.e., number of guilds that interact with the fishery) and gives all guilds in the fishery equal weight, though the weighting of individual bycatch guilds could be modified if so desired by CDFW. By contrast, fisheries with more bycatch guilds score higher using the cumulative method. The cumulative method also gives greater emphasis to guilds that score relatively high and are therefore relatively more at risk from the fishery.

Two of the bycatch ERA attributes were weighted to reflect their relative importance. One sensitivity attribute (release mortality) and one exposure attribute (magnitude) were each weighted to represent 50% of the total score among all attributes within each axis. This decision was made based primarily on the feedback of stakeholders and CDFW, who felt that the risk associated with these attributes best matched their understanding of how fisheries affected bycatch. The relative weighting of bycatch attributes can be further modified as needed (e.g., by choosing to weight release mortality at 50%, magnitude at 25%, or choosing different attributes altogether).

Relative weighting was not implemented among bycatch guilds because doing so would require a subjective value judgement. Options exist for displaying the results that can highlight fisheries that interact with special status species or which interact with higher numbers of bycatch guilds (see section ***3.2 Results*** for examples of this).

Graphical Display of Results

Results are represented most simply by ecosystem component-specific (target, bycatch, habitat) figures that display relative risk among targets and units of analysis, or among bycatch or habitat groups within a target or unit of analysis (Figure 4). Sensitivity and Exposure scores combine to create an overall risk score, with absolute and relative risk scores easily interpreted using contour lines of equivalent risk drawn at intervals ranging from 1-4. For bycatch results, the size of the dots on the figure indicates how many guilds with protected status (maximum = 3) contributed to the overall score for a target or unit of analysis. For habitat results, the size of the dots on the figure indicates how many groups contributed to the overall score for a target or unit of analysis.

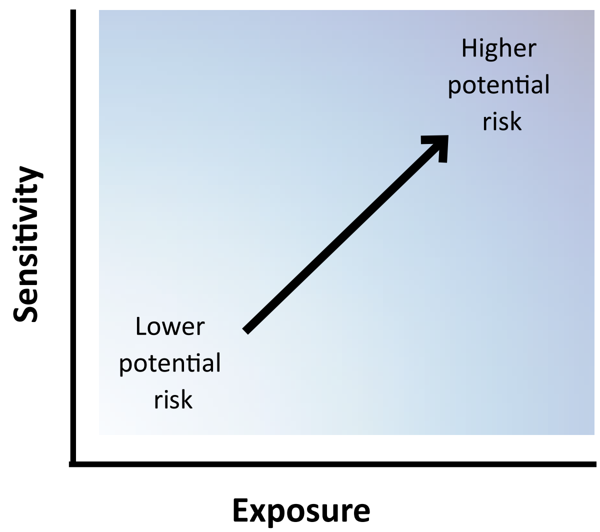


Figure 4. A generalized representation of how ERA results can be interpreted.

Data Quality

As part of this pilot, data quality was scored for every attribute and a written rationale for the attribute was provided. Data quality was not, however, integrated into any final results because limited time and effort were focused on finalizing results for the three ecosystem components. The project team discussed options for assessing data quality and stakeholders provided feedback as well. The treatment of data quality remains as one of the key decision points for the State or other users to consider in the future. There are well-established methodologies and the pilot tool can easily incorporate any of the options, since the data are readily available, once a decision has been made. The options for this key decision are discussed in ***Section 4: Next Steps***.

3.2 Results

The results presented in this report represent the final pilot results for the piloting and testing of this ERA tool. We produced and updated draft results throughout the iterative tool development process to help us understand if the tool was meeting its intended goal - to meet the State's prioritization needs with scientific rigor. The final pilot results are presented to help understand how the tool works and how results should be interpreted if the tool is implemented.

These results do not indicate a mandate for management action. Rather, they indicate a potential risk that should be examined further by users of the tool to determine whether and if a management action is needed. We piloted nine units of analysis, representing five fished species. This ERA tool could be used to score the remaining 36 fisheries for which PSAs were completed. Along with the PSA results, the 45 ERAs could then be used to help CDFW prioritize these fisheries for management actions.

3.2.1 Target Results

Of the nine fisheries assessed, relative risk to target species was greatest for white sturgeon in the sport hook and line fishery, followed by California halibut in all four fisheries (Figure 5). For all five of these fisheries, relatively high risk scores resulted from high scores for nearly all exposure attributes. Relative risk to California spiny lobster from trap and sport/hoop fisheries and to kelp bass from the hook and line fishery was similar to relative risk to California halibut from its four fisheries, but due to somewhat higher sensitivity scores rather than exposure scores. For lobster, high fishing mortality, behavioral response, and age at maturity scores led to high sensitivity scores, whereas for kelp bass sensitivity scores were relatively high because of population connectivity and breeding strategy considerations, in addition to their behavioral response to the fishery. Pacific herring exhibited the lowest relative risk due to the commercial gill net fishery, with low scores for most exposure and sensitivity attributes.

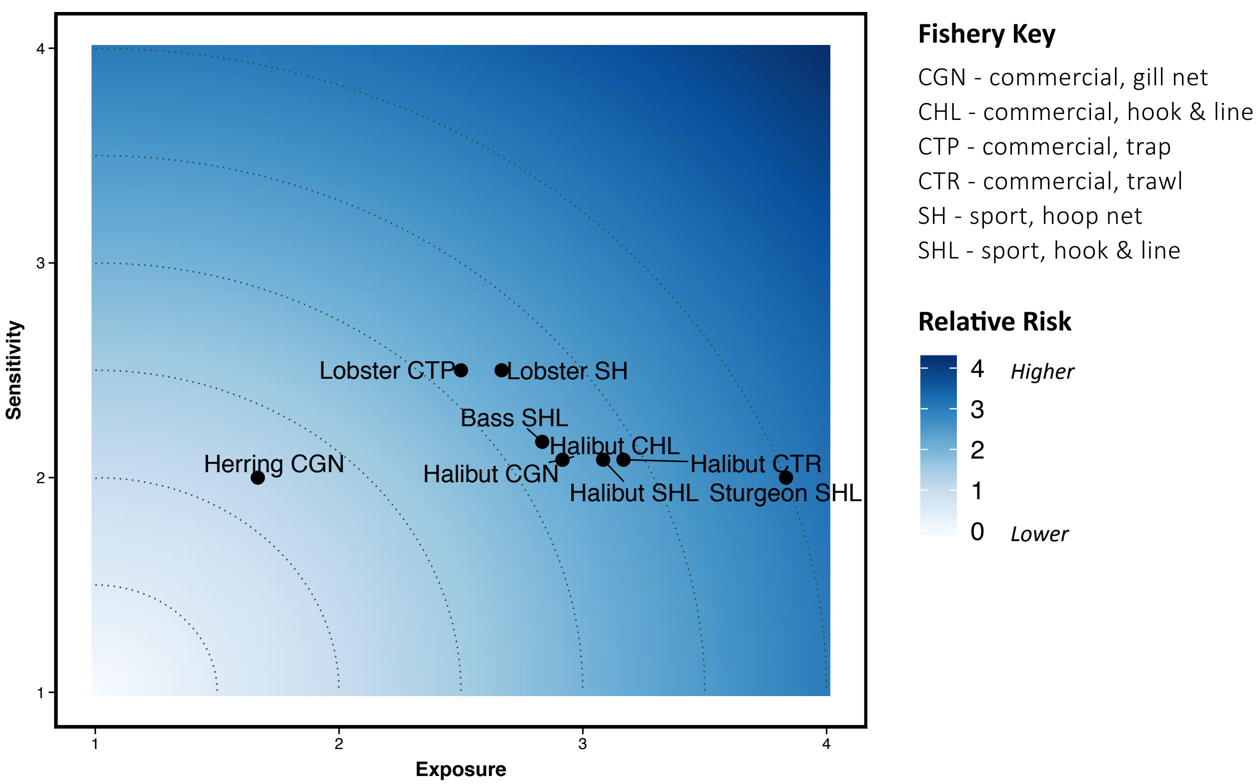


Figure 5. Target risk assessment results for the ERA pilot.

3.2.2 Bycatch Results

The rank ordering of relative cumulative risk to bycatch guilds differed from that of risk to target species (Figure 6). Specifically, the California halibut commercial gill net and trawl fisheries posed the greatest relative cumulative risk. This result emerged because both fisheries interact with six of the ten bycatch guilds, more than in the other fisheries. In the case of the commercial gill net fishery, relative cumulative risk to bycatch guilds was caused by the high sensitivity scores for other flatfishes, pelagic finfishes, non-pelagic finfishes, and threatened and endangered species and/or overfished rockfishes. The cause of high relative cumulative risk for bycatch guilds due to the California halibut commercial trawl fishery was more variable, with some guilds like marine mammals that had high sensitivity scores and others like flatfishes with high exposure scores. Intermediate relative risk scores for bycatch associated with the sport hook and line fisheries for white sturgeon and kelp bass resulted from their interactions with five bycatch guilds each. For both fisheries, non-pelagic finfishes were highly exposed, but not very sensitive, whereas other bycatch guilds were expected to be moderately exposed and sensitive. The remaining five fisheries exhibited much lower relative cumulative risk to bycatch guilds, largely because those fisheries interact only with one or two bycatch guilds. It is important to note that since the Bycatch ERA utilized the cumulative approach, the final results were more heavily influenced by the number of bycatch guilds that interacted with a fishery than by individual attribute scores.

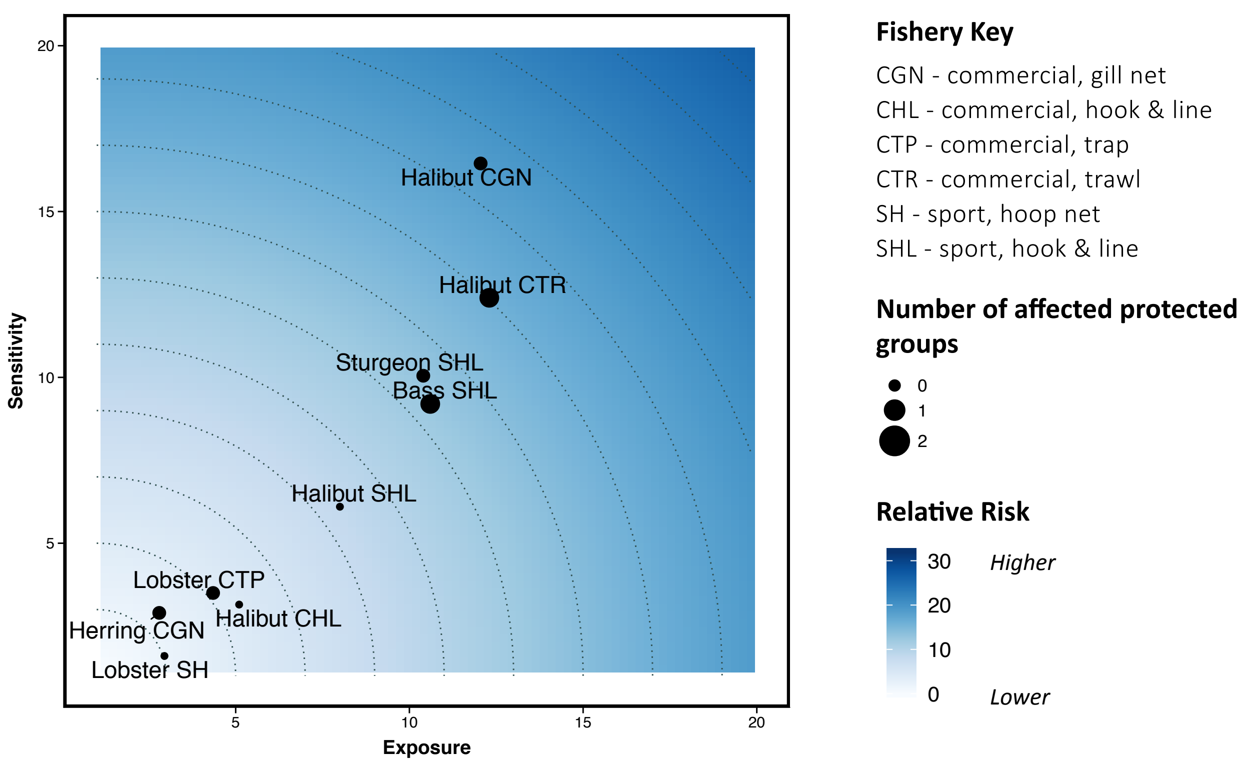


Figure 6. Target risk assessment results for the ERA pilot. Point size indicates the number of bycatch guilds with protected status affected by each fishery (maximum possible was three).

3.2.3 Habitat Results

Relative risk to habitats was greatest for those affected by the California halibut commercial trawl fishery, which included nearshore soft bottom and habitat-forming marine invertebrates (Figure 7). While these two habitats were both highly exposed, neither was expected to be particularly sensitive. Compared with the risk assessment for bycatch groups, the remaining eight fisheries did not show as much variation in risk score for habitats. Habitats influenced by the commercial gill net fishery for California halibut showed the greatest relative risk of those in an intermediate risk group, which also included the two California spiny lobster fisheries, the commercial gill net fishery for Pacific herring, and the sport hook-and-line fishery for white sturgeon. Notably, the two California spiny lobster fisheries affect the most habitats, including nearshore hard and soft bottom, marine vegetation, and invertebrates. The lowest relative risk to habitats emerged for three hook-and-line fisheries: the sport fishery for kelp bass and both the commercial and sport fisheries for California halibut. Of the three habitats influenced by the kelp bass fishery, only marine vegetation exhibited somewhat high exposure and sensitivity scores.

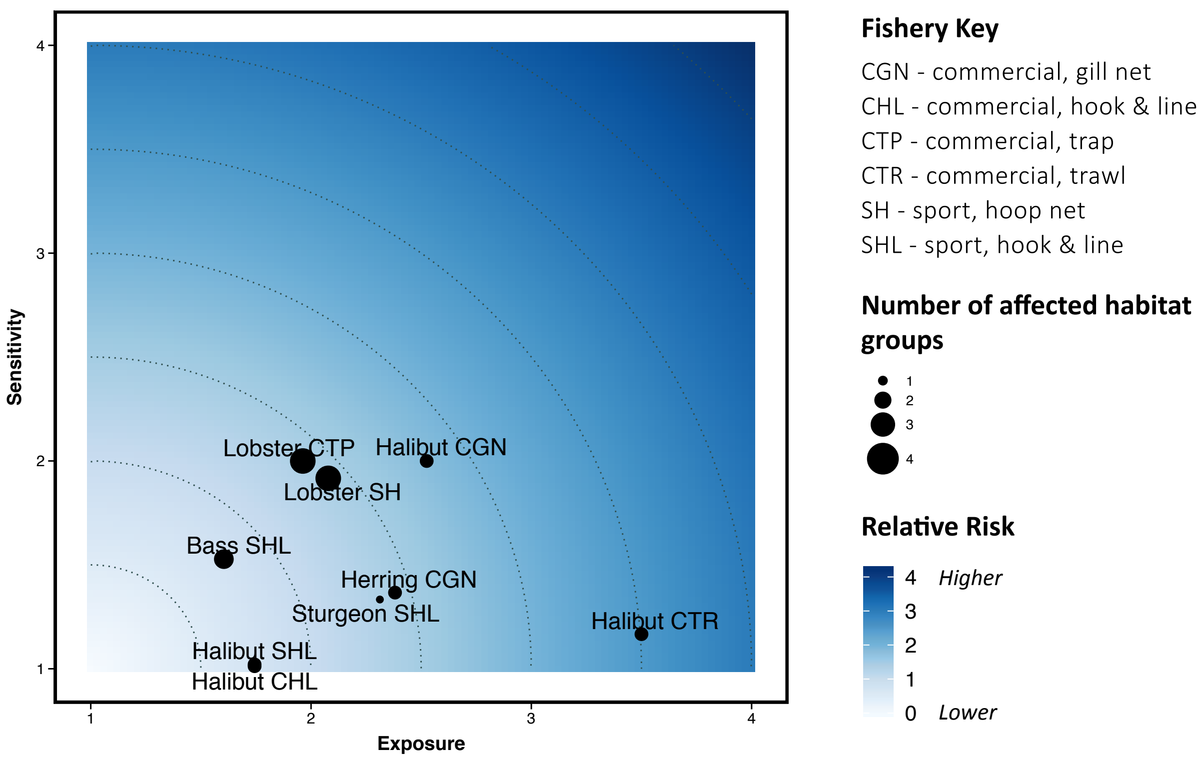


Figure 7. Habitat risk assessment for the ERA pilot. Point size indicates the number of habitat groups affected by each fishery (out of 10).

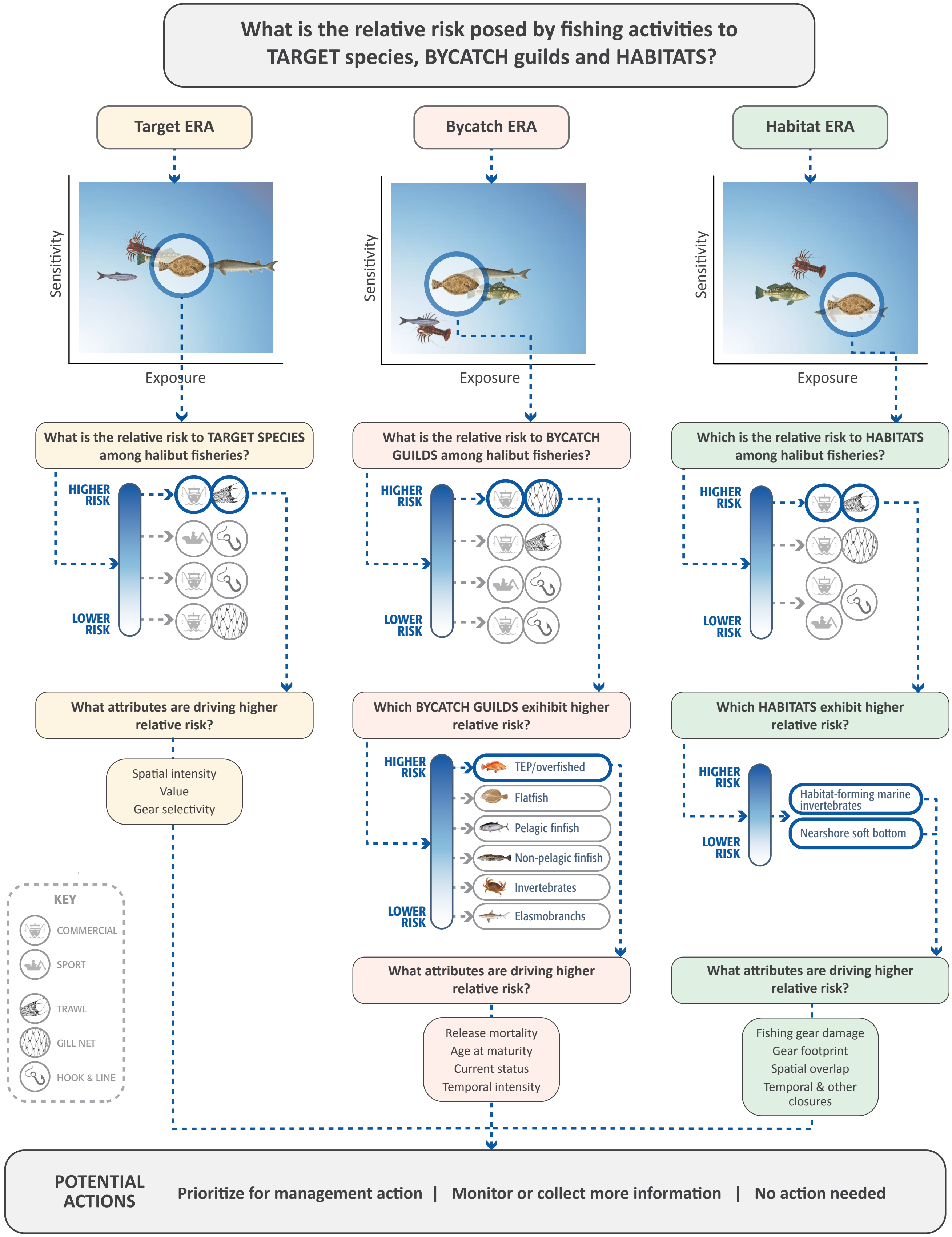


Figure 8. Results analysis demonstration for California halibut.

Going forward, it is within the purview of CDFW or other potential users to consider whether and if this pilot ERA meets their needs. This pilot test involved many key decisions. Several others remain should CDFW choose to implement the ERA in whole or in part. This section outlines those key decisions, considerations and options for future use of the tool.

4.1 Key Decision Points for Tool Refinement and implementation

Many decisions regarding tool development and implementation were agreed upon by the project team with feedback from stakeholders.

- **Data Quality consideration** (discussed in *Section 3: Methods*). Before implementation, we recommend deciding on a preferred method for incorporating data quality information. This information is helpful for interpreting results, understanding data gaps, and mobilizing public and private priorities for research and monitoring. We have summarized the three main options (although variations of each exist) and considerations for data quality analysis below. However several remain and are discussed below.

    1. **Keep data quality scores independent from results.** In this option, data quality scores are analyzed but do not impact the overall score of the fishery itself. This separate analysis allows for an understanding of the relative level of data quality in each fishery and can also be used when interpreting results. Furthermore, the independent data quality scores can be used to identify knowledge gaps related to certain attributes, fisheries, and/or ecosystem components. The option to keep data quality scores independent was used in the NOAA PSA scoring. However, we recommend that the data quality scores be integrated into the results figure for easier interpretation instead of creating a separate graph of data quality scores as was presented in the NOAA PSA MRAG report (MRAG 2016) (Figure 9).

    2. **Low data quality fisheries are weighted higher.** In this approach, fisheries that receive lower data quality scores are weighted more heavily overall. This approach was developed by the creators of PSA and is considered to be more 'precautionary' (Hobday et al., 2007; Hobday et al., 2011). While it has been adopted by others, the NOAA PSA departed from this approach in its application.

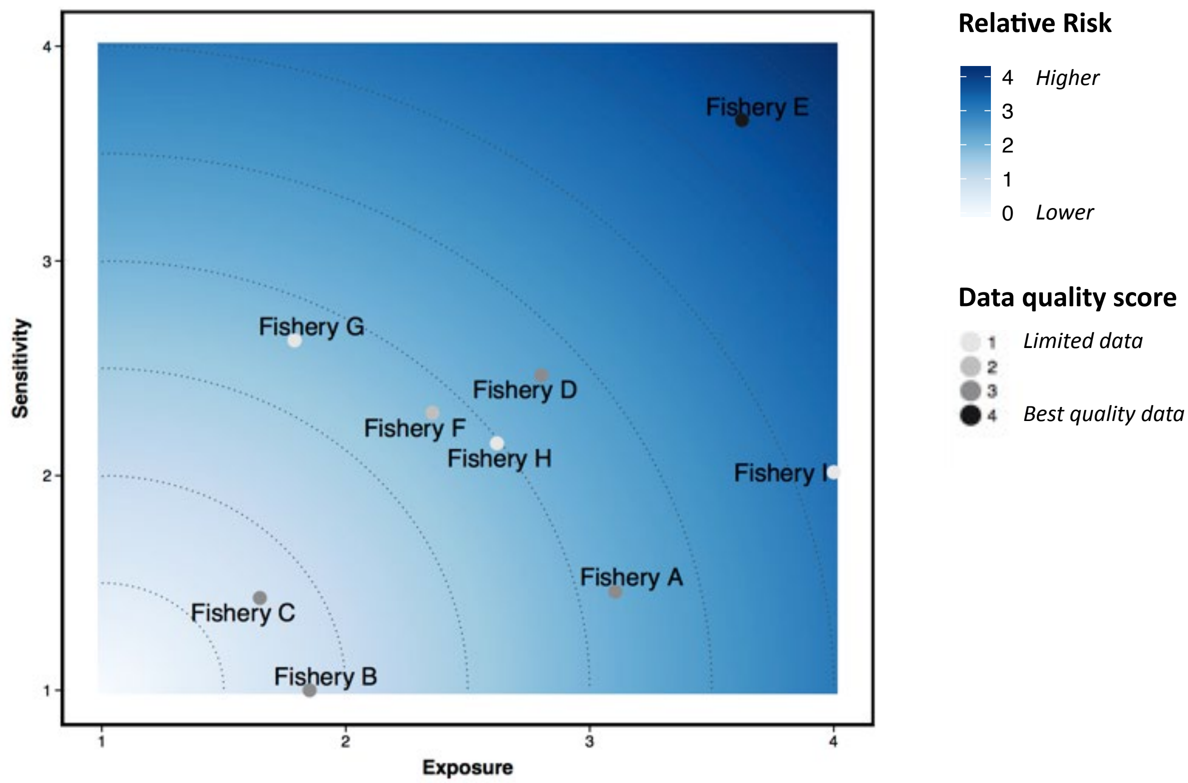


Figure 9. Sample results with data quality scores integrated into the figure.

3. **Higher data quality attributes are weighted higher in overall score.** In the previous application of the Samhouri and Levin (2012) ERA method, attributes that were scored with high data quality were given a higher weight in the overall risk score for a Unit of Analysis.

- **Create open access scoresheet and automated results analysis.** Once key refinements and decisions have been made, we recommend that the tool be structured into a format that is user-friendly and automates the analyses and results. This could be accomplished through either an automated spreadsheet and/or web-based app utilizing the methods and R code contained in Appendix XX.

- **Timeline for updates and addition of fisheries.** We have developed an ERA that is based on best practices, and is transparent and repeatable. This means that as new information becomes available, new fisheries need assessment, or as time progresses, the State can add or reassess fisheries relatively quickly. Over time, this tool becomes much faster to utilize, especially for fisheries previously assessed where the user is just re-evaluating changes in attribute scores. Stakeholders emphasized that any prioritization tool should be updated periodically, rather than conducted as a one-time analysis. We recommend consideration be made as to whether and how frequently to re-assess or add new fisheries to the analysis as part of their ERA implementation plan, and note that some attributes will require more frequent updating (e.g., current landings trend and management strategy for target ERA) than others (e.g., age at maturity for target ERA).

- **Definition of bycatch.** The bycatch ERA can accommodate different definitions of bycatch. Whatever definition is chosen must be adhered to and implemented consistently by the fishery experts conducting the scoring. For the purposes of the pilot ERA, bycatch was defined as “catch that is returned to the water.” Under this definition, sub-legal and supra-legal sized individuals of the target species are considered and scored as bycatch, as are individuals that are intentionally released even though they can legally be retained (catch-and-release fishing) . This scoring decision could potentially inflate bycatch risk for a fishery that may not typically be considered to have high rates of bycatch.

- **Process for scoring.** There is a wide array of literature and methods for utilizing expert judgment to conduct risk assessments. For the pilot, OST followed some of the best practices as described in Burgman (2005), but not others due to the preliminary nature of the work. Many ERAs use the modified delphi version as described in Burgman (2005). In this method, users are trained and briefed on the tool, then score the assessment, discuss their scores with others, follow-up with independent experts, then choose or combine to make final scores. We recommend that users review the Delphi method and make informed decisions about how scoring is completed beyond the pilot. We also recommend that multiple experts score each Unit of Analysis to incorporate different opinions that may lead to variability among attribute scores, or have experts convene to discuss and either agree upon or make changes to scores based on discussion.
- **Regional assessment of fisheries.** For the ERA pilot, the project team assessed state marine fisheries, i.e. the scale of our assessment was for fisheries operating within state waters with no geographical partitioning. However, during the stakeholder workshops, the project team received feedback that a regional approach for some fisheries may be more appropriate. For example, some fisheries, within the same sector and using the same gear, may operate at different scales and have different bycatch species north and south of Point Conception. This practice could result in different levels of relative risk between locations. The ERA pilot tool can accommodate different definitions of fisheries (or Units of Analysis) without changing the tool itself. Therefore, it can analyze fisheries any way the user chooses to define them.

4.2 Key Decision Points for PSA vs. ERA for Target Fisheries

For the information gathering phase of the MLMA Amendment, there were two options piloted for prioritizing target species for impacts from fishing activity. The PSA target species analysis was requested by CDFW and the target ERA pilot component was pursued by OST and NOAA to provide another option alongside the bycatch and habitat ERAs. Both of these tools represent scientifically sound options for the State to consider.

As a next step, CDFW will evaluate the usefulness of both of these tools for consideration as part of the amended Master Plan. While both tools have similar structure, methodologies, and goals, there are differences to consider when selecting a tool for future use (Table 4). There are also options for combining the PSA and ERA into a single tool and for transitioning between tools over time (Box 6).

4.3 Key Decision Points for Stakeholder Engagement

To increase the probability of success, CDFW is encouraged to consider multiple approaches to stakeholder engagement and decide upon the best approach given available resources, capacity, and priorities, before the implementation of any risk assessment. Best practices for ERA development and implementation involve stakeholders (Hobday et al. 2011, Fletcher 2005). In general, stakeholder engagement can lead to better data and knowledge than academic scientists or managers can generate alone. Fishermen and other stakeholders often have distinctive insights and information that can greatly inform the results of an ERA. Their involvement in the scoring process of an ERA also builds trust and buy-in to the results of the tool. Typically, the level of effort involved in engaging stakeholders in ERA processes decreases over time, as has been the case in many instances of stakeholder participation in ERAs, particularly in Australia. Over time, less effort is required for stakeholders to learn and understand the tool itself, and often times only a few attributes (ones with new information or that are contentious) require ongoing or regular updates or discussion as fisheries are revisited.

Table 4. Comparison of considerations for the NOAA PSA and pilot ERA for target species.

Consideration	NOAA PSA	Pilot ERA (adapted from Samhouri and Levin, 2012)
Scientifically rigorous	Yes	Yes
Independently peer-reviewed	Yes	Previous versions of the tool were peer-reviewed
Established methodology	Yes	This version of tool is not yet established
Number of fisheries completed for CA	45	9
Spread of final scores	Less	More
Ability to be further customized to consider stressors other than fishing	No	Yes
Considers MPA network	Not explicitly	Yes
Customized for California	No, customized AUS methodology for federal U.S. fisheries	Yes
Participation	Developed in consult with NOAA fishery scientists	Developed in consult with NOAA and CDFW fishery scientists and stakeholders
Publicly accessible spreadsheet with automated results	Yes	No, would need to be created

As part of this pilot project, the project team convened two stakeholder workshops to introduce the ERA tool while it was still under development (Appendix A). The primary goal for seeking input from stakeholders at this early stage was to ensure the tool was developed to reflect stakeholder priorities and needs. Engagement also offered an opportunity to share information about the ERA process and its potential role in supporting fisheries management in California. Visit the OST webpage (here) for the project for a summary of key themes and highlights that includes an overview of discussion topics, key questions, and identified next steps that emerged from both workshops, as well as input received during informal discussions with participants.

During the stakeholder workshops, participants expressed interest in helping to score fisheries in the future if CDFW were to adopt an ERA tool for prioritizing fisheries and recommended several approaches to stakeholder involvement (here). There are different approaches to stakeholder engagement, which vary in the level and timing of involvement by stakeholders. Each of these approaches must be examined in light of the current needs and capacity of CDFW and it's partners. Not all of the options may be feasible. Based on feedback from the workshops, examples and lessons learned from stakeholder engagement for other ERAs, and considerations about efficiency and capacity of CDFW, the following are several approaches to stakeholder engagement for CDFW's discussion and consideration:

- Draft ERA scores and spreadsheets could be made publicly available online and stakeholders could provide feedback through written comments or submit a completed score sheet to be considered CDFW.
- Scoring panels could be created for each fishery and those CDFW fishery experts in charge of scoring a

BOX 6. OPTIONS FOR TARGET SPECIES PRIORITIZATION THAT COMBINE OR TRANSITION THE NOAA PSA AND PILOT ERA.

- **Combine both methods: Take unique elements of the target ERA and insert into NOAA PSA**. Unique attributes (such as the MPA attribute) from the customized Target ERA that are not part of the NOAA PSA would be added to the analysis of the PSA.

  Considerations:

  - Creates a customized PSA approach that considers aspects of stakeholder feedback from workshops as well as key state assets such as the MPA network.
  - Creates an analysis with more attributes and therefore information about potential risk from fishing impacts.
  - No longer has a readily available open access nature of the tool itself (NOAA PSA available online as excel workbook).
  - This combined version was not tested, however each of its sub-components (NOAA PSA and Target ERA) were tested.
  - Care needs to be taken in the cross-walk from ERA Exposure and Sensitivity attributes to PSA Productivity and Susceptibility attributes.
  - Need to re-score and reanalyze results, which may not be a time-consuming undertaking since much of the structure is already in place

- **Phased: Transition from NOAA PSA to ERA** Can utilize the ERA, if that is the preferred tool, over time to limit any cumbersome front end of implementation issues.

  Considerations:

  - Utilize results of PSA right now, but moving forward use the ERA instead (assuming the State plans to continue to re-evaluate fisheries and evaluate new ones).
  - Effort to conduct Target ERA would be more time consuming than updating PSA scores.
  - PSA and ERA scores could be made to be "equivalent" (i.e. a score of 1-1.5 on PSA is the same as the low risk score of 1-2 on ERA) to simplify this transition.
  - Allows the State to utilize the PSA scores now, with no further modification.
  - If using PSA in the short term, target, bycatch, and habitat cannot be scored on the same scale immediately (however, they can still be placed into high, medium, and low risk score bins).

fishery would be required to either conduct or review their scores with a diverse group of stakeholders (e.g., fishermen, academic scientists, and environmental NGOs). CDFW fishery experts would be responsible for considering stakeholders' recommendations for scoring changes and documenting whether a scoring request was approved or denied with rationale.

- CDFW could choose to hold briefings and/or webinars with stakeholders to share information and final results without soliciting feedback or making changes to the scores based on stakeholder knowledge.
- Similar to the ERA workshops held during the pilot, CDFW could host workshops to share, discuss, and refine scores for fisheries with stakeholders. For example, CDFW could present draft spreadsheets and work with stakeholders to complete final scoring, or could score fisheries in real time with stakeholders. The former approach could be more suitable for an ERA tool that includes attributes that are not based on values or information available in peer-reviewed literature values (e.g., fecundity is a literature-based attribute, but spatial intensity is not and could therefore benefit from multiple types of knowledge to determine a more accurate score).

5. Conclusions

This pilot ERA process resulted in a tool that addresses potential management needs and can be conducted relatively efficiently while remaining scientifically rigorous. The process we used to create the pilot ERA was highly iterative and collaborative between NOAA, OST, CDFW, and incorporated stakeholder input. The result is a tool that can largely be conducted by CDFW should sufficient resources and capacity be available.

CDFW can now assess if the tool meets their current management needs to prioritize fisheries based on the three ecosystem components - target, bycatch, and habitat. Key decision points for potential future use of the tool pertain mostly to tool implementation and stakeholder engagement, rather than tool development.

This process demonstrated a way for CDFW to select an existing ERA for customization to meet their specific management goals and ecosystem features. This pilot ERA and process can be utilized by others to meet similar goals or to select and customize their own ERA efficiently.

References

Arkema, K.K., Verutes, G., Bernhardt, J.R., Clarke, C., Rosado, S., Canto, M., et al. 2014. Assessing habitat risk from human activities to inform coastal and marine spatial planning: a demonstration in Belize. Environmental Research Letters 9: 114016.

Battista, W., Narr, K., Sarto, N., and Fujita, R. 2017. Comprehensive assessment of risk to ecosystems. Fisheries Research 185: 115-129.

Burgman, M., 2005. Risks and decisions for conservation and environmental management. Cambridge University Press, Cambridge, UK.

FAO. 2003. The ecosystem approach to marine capture fisheries. FAO Technical Guidelines for Responsible Fisheries, No. 4 (Suppl. 2): 112 pp.

Fletcher, W.J., 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES Journal of Marine Science 62: 1576-1587.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., et al. 2008. A global map of human impact on marine ecosystems. Science 319: 948-952.

Hobday, A.J., Smith, A., Webb, H., Daley, R., Wayte, S., Bulman, C., Dowdney, J., 2007. Ecological risk assessment for effects of fishing: Methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra.

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A. et al. 2011. Ecological risk assessment for the effects of fishing. Fisheries Research 108: 372-384.

Link J. S., Brodziak J., Edwards S., Overholtz W., Mountain D., Jossi J., Smith T., et al. 2002. Marine ecosystem assessment in a fisheries management context. Canadian Journal of Fisheries and Aquatic Sciences 59: 1429-1440.

O.M., Martone, R., Hannah, L., Grieg, L., Boutillier, J. and Patton, S. A risk-based framework for ecosystem-based oceans management. CSAP Working Paper 2012/P46.

Morrison, J.P, Sharma, A.K., Rao, D., Pardo, I.D., Garman, R.H., Kaufmann, W., and Bolon, B. 2015. Fundamentals of translational neuroscience in toxicology pathology. Toxicology Pathology 43: 132-139.

MRAG Americas. 2016. Productivity and susceptibility analysis for selected California fisheries. Report to California Ocean Science Trust and California Department of Fish and Wildlife. 55 pp.

California Ocean Science Trust. 2014. Ecological Risk Assessments: A Roadmap for California Fisheries. Available online http://www.oceansciencetrust.org/wp-content/uploads/2016/11/Ecological-Risk-Assessments-Roadmap-FINAL.pdf

Patrick, W.S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., et al., 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. Fishery Bulletin 108: 305-322.

Samhouri, J.F., and Levin, P.S. 2012. Linking land- and sea-based activities to risk in coastal ecosystems. Biological Conservation 145: 118-129.

Stelzenmüller, V., Lee, J., South, A., Rogers, S., 2010. Quantifying cumulative impacts of human pressures on the marine environment: a geospatial modelling framework. Marine Ecology Progress Series 398: 19-32.

Williams, A., Dowdney, J., Smith, A.D.M., Hobday, A.J., and Fuller, M. 2011. Evaluating impacts of fishing on benthic habitats: a risk assessment framework applied to Australian fisheries Fisheries Research 112: 154–167.

Winemiller, K.O. 1989. Patterns of variation in life history among South American fishes in seasonal environments. Oecologia 81: 225-241.

Zhou, S. and Griffiths, S. 2008. Sustainability Assessment for Fishing Effects (SAFE): A new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. Fisheries Research. 91. 56-68.

Appendix A: Stakeholder Workshops to Explore ERAs as a Potential Prioritization Tool to Support Fisheries Management in California

Ocean Science Trust hosted two stakeholder workshops, one in northern California and one in southern California, were held in June and July 2017 to explore the role that ERAs may have in prioritizing and informing the management of California fisheries. Fisheries experts were invited to:

- **Review draft ERA scoring for nine pilot fisheries** as examples for considering target species, along with habitat and bycatch risks, and provide feedback on the tools related to CDFW and stakeholder priorities.
- **Explore PSA**, another type of risk assessment, which focuses on the risk of fishing activity to fisheries, and its preliminary results.
- **Learn about the Marine Life Management Act (MLMA) Master Plan amendment process**, including how ERA may support CDFW's broader prioritization goals.

Workshops were held in the following locations:

Southern California: Long Beach	**Northern California: Santa Rosa**
Date: Thursday, June 15	Date: Thursday, July 27
Time: 9:00 am – 3:00 pm	Time: 9:00 am – 3:00 pm
Location: Veteran's Park Community Center	Location: Justice Joseph A. Rattigan Building

Workshop resources

Handouts

- Agenda[1] (here)
- Productivity Susceptibility Assessment Overview[2] (here)
- Summary of Workshop Key Themes and Discussion[3] (here)
- Draft pilot ERA score sheet[4] (here)

Powerpoint presentations

- Introduction slides[5] (here)
- Productivity Susceptibility Analysis slides (45 fisheries)[6] (here)
- Ecological Risk Assessment slides (9 pilot fisheries)[7] (here)

[1] http://www.oceansciencetrust.org/wp-content/uploads/2017/06/ERA_FINAL_WorkshopAgenda_052917.pdf

[2] http://www.oceansciencetrust.org/wp-content/uploads/2017/06/PSA-Overview-2pager.pdf

[3] http://www.oceansciencetrust.org/wp-content/uploads/2017/09/ERA_KeyThemesSummary_Final.pdf

[4] http://www.oceansciencetrust.org/wp-content/uploads/2017/09/Final-draft-pilot-ERA-scoresheet.xlsx

[5] http://www.oceansciencetrust.org/wp-content/uploads/2017/09/ERA-Workshop-Intro-slides-8.8.17.pdf

[6] http://www.oceansciencetrust.org/wp-content/uploads/2017/09/PSA-ppt-8.8.17-.pdf

[7] http://www.oceansciencetrust.org/wp-content/uploads/2017/09/Risk-assessment-Santa-Rosa-workshop-as-presented-8.8.17.pdf

Appendix B: Attribute Tables

Table 5. Exposure attributes, definitions, and scoring categories for target (T), bycatch (B), and habitat (H). * indicates that attribute does not vary across fisheries.

	Description	Sensitivity 4 (High)	3	2	1 (Low)
Low resistance factors					
Behavioral response[T,B]	Population-wide behavioral effect of the fishery (or fishing gear) on a species	Behavioral response significantly increases impact (e.g., baited hook/pot/trap, lighted squid boats - attracted into it)	Behavioral response increases impact somewhat (e.g., schooling behavior - herring)	Behavioral response does not change impact (e.g., sedentary species)	Behavioral response reduces impact (e.g., built in inefficiency or ability of a species to get out of a gear)
Current status[H]	The regional status of the habitat; increasingly critical status signifies a decrease in the ability of the habitat to recover from the impacts of the pressure	High concern (endangered or threatened status or thought to be imperiled); unrecognizable or substantially degraded compared to historical status	Habitat is highly degraded, but either has no official status or is undergoing significant or successful management efforts to rebuild or restore	Moderate to low concern (e.g., impact studies exist but do not reveal major problems); somewhat degraded compared to historical; efforts underway to rebuild the habitat	No concern; negligible difference from historical
Fishing mortality[T]	The proportion of the total population lethally removed from the fish stock by fishing activities.	> 0.40	0.31-0.40	0.20-0.30	<0.20
Release mortality[B]	Fish survival after capture and release varies by species, region, and gear type or even market conditions, and thus can affect the susceptibility of the stock.	Probability of survival < 25%	Probability of survival 26-50%	Probability of survival 51-75%	Probability of survival > 75%
Slow recovery factors					
Age at maturity[T,B,*]	Age at maturity - population-wide average age at maturity; greater age at maturity corresponds to longer generation times and lower productivity	>10 years	6-10 years	2-5 years	<2 years
Breeding strategy[T,B,*]	The breeding strategy of a stock provides an indication of the level of mortality that may be expected for the offspring in the first stages of life. Additional information in Winemiller 1989.	0-1 or External fertilization and no parental care with known low successful reproduction rates	2 or External fertilization and no parental care	3 or Internal fertilization or parental care but not both	≥4 or Internal fertilization and parental care
Fecundity[T,B,*]	The population-wide average number of offspring produced by a female each year	<10e1	10e1-10e2	10e2–10e3	>10e3
Population connectivity[H]	For biotic habitats, realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability; based on monitoring surveys, and population genetic or direct tracking estimates. Abiotic habitats should be scored as 1.	There is a recognized biogeographically boundary for all or most individuals within the state (e.g. Point Conception); the habitat or some of the organisms that form it are listed species or have protected status.	There is a recognized biogeographically boundary for all of or most individuals within the state (e.g. Point Conception); the habitat or some of the organisms that form it are NOT listed species or have protected status.	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has either an egg or larval dispersal period less than 1 month or has no egg and larval dispersal period	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has an egg or larval dispersal period of 1 month or greater.
Population connectivity[T,B,*]	Realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability; based on monitoring surveys, and population genetic or direct tracking estimates	There is a recognized biogeographically boundary for all or most individuals within the state (e.g. Point Conception); one or more population(s) is identified as DPS or EU	There is a recognized biogeographically boundary for all of or most individuals within the state (e.g. Point Conception); no populations are identified as DPS or EU.	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has either an egg or larval dispersal period less than 1 month or has no egg and larval dispersal period	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has an egg or larval dispersal period of 1 month or greater.
Potential damage to habitat from fishing gear[H]	Within the footprint of the fishery: The potential modification of habitat when exposed to a fishery (gear, chains, anchors, boats, etc.).	Potential modification to habitat structure is caused by fishing activity using bottom trawl or beam trawl or new gear with unstudied effects	Potential modification to habitat structure is caused by fishing activity using traps on strings with ground lines and weights (e.g. spot prawn, hagfish fisheries), gill nets, or purse seine	Potential modification to habitat structure is caused by trap and hoop nets with individuals lines and floats (e.g. lobster, Dungeness crab), or occasionally by anchor or chain damage from vessels not drifting when hook-and-line or hand-collection type gear.	No or insignificant potential modifications to habitat structure caused by any of these gears used: hook-and-line, clam fork, abalone iron, urchin rake, hand collection (e.g. sea cucumber fishery), A-frame, midwater trawl
Recovery time[H]	For biotic habitats, we refer to recovery time of the habitat as a whole (e.g., a mature kelp forest) rather than recovery time of individuals. For abiotic habitats, shorter recovery times for habitats such as mudflats decrease the sensitivity of exposure to human activities, whereas for habitats made of bedrock, recovery will occur on geological time scales.	Recovery time >100 years	Recovery time >10 years	Recovery time 1-10 years	Recovery time <1 year

	Description	Sensitivity 4 (High)	3	2	1 (Low)
Spatial and temporal factors					
Spatial intensity[T,B]	The overlap between the regional abundance of the species and the relative intensity of the target fishery throughout the region (consider both areal and vertical overlap, but not MPA coverage)	Very High overlap (>40%) between species and fishery	High overlap (>20-40%) between species and fishery	Moderate overlap (10-20%) between species and fishery	Low overlap (<10%) between species and fishery
Spatial overlap[H]	The regional status of the habitat; increasingly critical status signifies a decrease in the ability of the habitat to recover from the impacts of the pressure	High concern (endangered or threatened status or thought to be imperiled); unrecognizable or substantially degraded compared to historical status	Habitat is highly degraded, but either has no official status or is undergoing significant or successful management efforts to rebuild or restore	Moderate to low concern (e.g., impact studies exist but do not reveal major problems); somewhat degraded compared to historical; efforts underway to rebuild the habitat	No concern; negligible difference from historical
Temporal intensity[T, B]	The proportion of the total population lethally removed from the fish stock by fishing activities.	> 0.40	0.31-0.40	0.20-0.30	<0.20
Release mortality[B]	Fish survival after capture and release varies by species, region, and gear type or even market conditions, and thus can affect the susceptibility of the stock.	Probability of survival < 25%	Probability of survival 26-50%	Probability of survival 51-75%	Probability of survival > 75%
Slow recovery factors					
Age at maturity[T,B,*]	Age at maturity - population-wide average age at maturity; greater age at maturity corresponds to longer generation times and lower productivity	>10 years	6-10 years	2-5 years	<2 years
Breeding strategy[T,B,*]	The breeding strategy of a stock provides an indication of the level of mortality that may be expected for the offspring in the first stages of life. Additional information in Winemiller 1989.	0-1 or External fertilization and no parental care with known low successful reproduction rates	2 or External fertilization and no parental care	3 or Internal fertilization or parental care but not both	≥4 or Internal fertilization and parental care
Fecundity[T,B,*]	The population-wide average number of offspring produced by a female each year	<10e1	10e1-10e2	10e2–10e3	>10e3
Population connectivity[H]	For biotic habitats, realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability; based on monitoring surveys, and population genetic or direct tracking estimates. Abiotic habitats should be scored as 1.	There is a recognized biogeographically boundary for all or most individuals within the state (e.g. Point Conception); the habitat or some of the organisms that form it are listed species or have protected status.	There is a recognized biogeographically boundary for all of or most individuals within the state (e.g. Point Conception); the habitat or some of the organisms that form it are NOT listed species or have protected status.	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has either an egg or larval dispersal period less than 1 month or has no egg and larval dispersal period	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has an egg or larval dispersal period of 1 month or greater.
Population connectivity[T,B,*]	Realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability; based on monitoring surveys, and population genetic or direct tracking estimates	There is a recognized biogeographically boundary for all or most individuals within the state (e.g. Point Conception); one or more population(s) is identified as DPS or EU	There is a recognized biogeographically boundary for all of or most individuals within the state (e.g. Point Conception); no populations are identified as DPS or EU.	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has either an egg or larval dispersal period less than 1 month or has no egg and larval dispersal period	There is not a recognized biogeographically boundary for all of or most individuals within the state (e.g. Pt. Conception), and the species has an egg or larval dispersal period of 1 month or greater.
Potential damage to habitat from fishing gear[H]	Within the footprint of the fishery: The potential modification of habitat when exposed to a fishery (gear, chains, anchors, boats, etc.).	Potential modification to habitat structure is caused by fishing activity using bottom trawl or beam trawl or new gear with unstudied effects	Potential modification to habitat structure is caused by fishing activity using traps on strings with ground lines and weights (e.g. spot prawn, hagfish fisheries), gill nets, or purse seine	Potential modification to habitat structure is caused by trap and hoop nets with individuals lines and floats (e.g. lobster, Dungeness crab), or occasionally by anchor or chain damage from vessels not drifting when hook-and-line or hand-collection type gear.	No or insignificant potential modifications to habitat structure caused by any of these gears used: hook-and-line, clam fork, abalone iron, urchin rake, hand collection (e.g. sea cucumber fishery), A-frame, midwater trawl

Appendix C: Draft ERA Scoring Spreadsheets

Direct download links to all of the individual draft ERA scoring spreadsheets by fishery can be found below and on the Ocean Science Trust website project page here: http://www.oceansciencetrust.org/projects/era/

- **All (.zip):** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/ERA-Scoresheets-2017-all.zip
- **Blank:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Blank-ERA-scoresheet-2017.xlsx

California halibut

- **Commercial, hook and line:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Halibut_com_HL_ERA-scoresheet-2017.xlsx
- **Sport, hook and line:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Halibut_rec_HL_ERA-scoresheet-2017.xlsx
- **Commercial, gill net:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Halibut_com_gill_net-_ERA-scoresheet-2017.xlsx
- **Commercial, trawl:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Halibut_com_trawl-_ERA-scoresheet-2017.xlsx

Kelp bass

- **Sport, hook and line:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Kelp_Bass_rec_HL_ERA-scoresheet-2017.xlsx

Pacific herring

- **Commercial, gill net:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Herring_comgill_ERA-scoresheet-2017.xlsx

Spiny lobster

- **Commercial, trap:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Spinylobster_com_trap_ERA-scoresheet-2017.xlsx
- **Sport, hoop net:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/Spinylobster_rec_hoop_ERA-scoresheet-2017.xlsx

White sturgeon

- **Sport, hook and line:** http://www.oceansciencetrust.org/wp-content/uploads/2017/10/White-Sturgeon_rec_ERA-scoresheet-2017.xlsx

Appendix D: Protocol for Tool Application & Analytical Methods

Protocol for Tool Application - A User's Guide to Calculating ERA Scores for California Fisheries

*the R coding packages referred to in this section are available for download on the project site at: http://www.oceansciencetrust.org/projects/era/

Background

Prior to data compilation and analysis, you will need to: 1) complete expert scoring for each fishery and unit of analysis (e.g., target, bycatch, habitat) of interest, 2) save each corresponding fishery/unit of analysis scoring spreadsheet as a .csv file, and 3) download and install R (https://www.r-project.org/), which will serve as the platform for analysis. Alternatively, you can download and install R-Studio (https://www.rstudio.com/) which is an interface for R that includes a console, syntax-highlighting editor that supports direct code execution, and tools for plotting, history, debugging, and workspace management. Because the ERA for California fisheries contained nine separate fisheries, each with three units of analysis (target species, bycatch groups, and habitat groups), 27 .csv files were generated. Each of these files should be located in the same folder, called "Input files*," as the R-code will navigate to this folder during scoring compilation and analysis. Four R-scripts are required: Compile scores, Risk code for bycatch, Risk code for habitats, and Risk code for target groups. Place each script in a folder labelled "Code*."

Data Compilation

The first step in processing scores is to compile all fishery data for each unit of analysis. Open the "Compile scores" script in R or R-Studio. You will need to call several "libraries" (which perform specific compilation, analytical, or graphing functions in the script) before you start. Most of these libraries will require additional "packages" that also must be installed (instructions: https://math.usask.ca/~longhai/software/installrpkg.html). Once all libraries and packages are successfully installed, you can start to run the script to compile scores. The initial step in this process requires some text editing in line 13 to change the path to match the location of your input files. The script contains helpful supplemental information and instructions throughout, all of which are indicated by a "#" symbol at the start of a line of code. You can include these statements when you run the script or omit them. R understands that these statements are text strings (not code) and will ignore this information. Rather than running the entire script at once, it is useful to run it in the indicated subdivisions to better follow and understand the procedure, and to pinpoint any errors as they arise. At line 247, you will need to identify the location of an "Output Files*" folder where the compiled scores .csv file will be created. Otherwise, you can run the code directly as written. Once this process is complete, you can begin analysis of each fishery unit.

Data Analysis

Each unit of analysis is analyzed separately using a distinct R script. Each script requires that you load libraries (and associated packages) and set the working directory to match that of your local computer. The first step in the process is to read in compiled scores and filter them to match the unit of analysis that you are analyzing. Run the script in the indicated sub-sections so that you can best understand the process and pinpoint any errors that may arise. For the target script, you will need to edit lines 87, 129, and 149 to indicate the intended location of the output files. In the bycatch script, edit lines 148, 227, 241, 261, and 278, and in the habitat script, edit lines 135, 187, 202, and 228. For each unit of analysis, results are output as .csv files, and also used to generate figures. These figures include:

1. **Target** – risk by fishery,
2. **Bycatch** – cumulative risk to all bycatch groups in each fishery, average risk to all bycatch groups in each fishery, risk panels by bycatch group for each fishery, and risk panels by fishery for each bycatch group, and
3. **Habitat** - average risk to all habitat groups in each fishery, risk panels by habitat group for each fishery, and risk panels by fishery for each habitat group.

All figures are saved as .pdf files, which allows for editing in Adobe Illustrator or similar vector graphics creation and editing software.

Short version:

1. Run the "Compile scores" script.
   - a.) For target species, run the "Risk code for target species" script.
   - b.) For bycatch groups, run the "Risk code for bycatch" script.
   - c.) For habitats, run the "Risk code for habitats" script

Analytical Methods

Defining Units of Analysis and Assessing Risk

We conducted scoring and analysis for five target species, including California halibut, California spiny lobster, kelp bass, Pacific herring, and white sturgeon. These species were selected by CDFW because of the diversity of habitat types, fishery types (commercial or recreational), and gear types that they represent. Multiple fisheries were analyzed for two of the target species, resulting in nine units of analysis as follows: four California halibut fisheries, two spiny lobster fisheries, and single fisheries targeting Pacific herring, white sturgeon, and kelp bass.

For each unit of analysis, we assessed the risk posed by each fishery to the target species, 10 bycatch groups, and 10 habitat groups. The risk assessment for each unit of analysis was based on the exposure and sensitivity of each target, bycatch, or habitat group (hereafter, focal component). Focal components that were relatively more exposed and more sensitive were considered to be at higher risk. CDFW experts quantified exposure and sensitivity based on the sets of attributes described below. We use the term "baseline" to refer to attributes that did not vary among fisheries. A single expert scored target, bycatch, and habitat for each unit of analysis, and completed the scoring for each fishery multiple times following discussions as a group to ensure the scoring categories were standardized. One fishery expert worked with the other fishery experts to review scores and ensure that the attributes were scored consistently.

The 10 bycatch groups and 10 habitat groups were chosen to be maximally representative while not overly encumbering expert scorers with an exhaustive list. Risk to a bycatch or habitat group was assessed for a representative species or feature within that group. Initial group definitions and orientation between axes were modified and finalized following interactive workshops with stakeholders. Bycatch and habitat groups not affected by a particular unit of analysis (fishery) were not scored by experts and were not included in analysis.

For bycatch, ten groups were initially suggested by CDFW to contain the full spectrum of species considered bycatch in California's marine fisheries, but to limit the number of groups so that scoring was not an unreasonable task. The groups were refined by the project team and stakeholders during workshops. We used the most frequently caught species within a group and scored it as appropriate. For seven of the 10 guilds, a bycatch group was scored if it represented greater than 1% of the catch of the target species by either weight or number for any species within that group. For the other three groups (Marine Mammals, Marine Birds, and Threatened and Endangered species and/or Overfished Rockfish), if there was any bycatch of these groups, we scored the most common species within the group. Sub- and supra-legals of the target species were scored as bycatch.

Ten habitat groups were selected based on knowledge of California coastal and oceanic ecosystems, management definitions of habitat utilized by CDFW, and availability of GIS mapping data, using the smallest number of groups feasible for efficiency. For fisheries that occur in multiple habitats, we estimated the percent of fishing activity that occurs in each habitat (sum = 100%) for use in subsequent analysis.

Exposure Attributes

Definitions and scoring categories for each exposure attribute are included in Appendix B.

Target

Experts assessed exposure of each target species to each fishery based on two baseline attributes, the value of the exploited species and MPA coverage (and/or other permanent spatial closure) in place to protect the species. In addition, experts determined exposure of each target species based on four attributes that did vary among fisheries, including: spatial intensity, temporal intensity, gear selectivity, and current landings trend and management strategy.

Bycatch

Two baseline attribute and four additional attributes were scored for bycatch groups. Current status and MPA coverage were considered baseline attributes. Non-baseline attributes included: magnitude, management effectiveness, spatial intensity, and temporal intensity.

Habitat

One baseline attribute (MPA coverage) and three additional attributes were scored for habitat groups. Non-baseline attributes included: management effectiveness, spatial overlap, and temporal closures.

Sensitivity Attributes

Definitions and scoring categories for each sensitivity attribute are included in Appendix B.

Target

Sensitivity of each target species to each fishery was scored by CDFW experts based on four baseline attributes and two attributes that varied among fisheries (Table 3). Baseline attributes included: age at maturity, breeding strategy, fecundity, and population connectivity. Behavioral response and fishing mortality were the non-baseline attributes.

Bycatch

Four baseline attributes and two additional attributes were scored for bycatch groups. Age at maturity, breeding strategy, fecundity, and population connectivity were baseline attributes. Behavioral response and release mortality were considered non-baseline attributes.

Habitat

Two baseline attributes and two non-baseline attributes were scored for habitat groups. Population connectivity and current status were the baseline attributes whereas non-baseline attributes included recovery time and potential damage to habitat from fishing gear.

Data Quality

Accounting for the quality of the data used to score attributes is a key component of any modern ERA. Because ERAs ask a user to generate scores for fisheries that are both data poor and data rich, the data used can range from expert opinion to formal stock assessments. Because it is important to understand how the attributes were scored, experts are asked to provide a rationale about why they chose a particular score. An expert can explain if the score was based on peer-reviewed literature, landings data, personal observation, or some other source. The rationale used in scoring is very important for interpreting results, for ensuring standardization in scoring rationale among experts, and for transparency with stakeholders. Because of the above, the experts are asked to assign each attribute score an additional data quality score. The data quality scores were adapted from the Monterey Bay National Marine Sanctuary application of the Samhouri and Levin (2012) methodology.

Analysis of Expert Scores

We developed a framework for evaluating the risk that fisheries will lead to negative effects on marine species or habitats over the next ca. 20 years (assuming management practices continue unchanged) based on two axes of information. The first axis was related to the exposure E of a species or habitat to a fishery, and the other axis was a conditional probability related to the sensitivity S of the species or habitat to the fishery, given its exposure. We define a negative effect as an unwanted outcome, here assumed to be the decline in abundance of a species or habitat.

Analyses were conducted to enable the presentation of different options for consideration by scientists and fisheries managers at CDFW and were ultimately tailored to best meet their needs. For all analyses, scores ranged from 1-4, with a 0 score indicating no interaction with a fishery or a very minor interaction (for habitats and bycatch species that do not interact with a fishery). This approach varies slightly from that used for the PSA, which ranged from 1-3 and did not specifically define a non-interaction score.

The relative risk R_i to species or group i was calculated as the Euclidean distance of the species or group from the origin in a space defined by exposure and sensitivity indices, or

$$R_i = \sqrt{(E-1)^2 + (S-1)^2} \quad (1)$$

Under this framework, the risk to a species or group increased with distance from the origin and each axis received equivalent weight in estimating risk. Values for each exposure attribute $a_{e,i}$ and sensitivity attribute as,i were determined by assigning a score ranging from one to four for a standardized set of A_e or A_s attributes (for the exposure and sensitivity axes, respectively). These scores were used to calculate an exposure or sensitivity index with each attribute weighted by a factor w_i (ranging from [0,1] with) related to its importance, as

$$E = \sum_{i=1}^{A_e} w_i a_{e,i} \quad (2)$$

and

$$S = \sum_{i=1}^{A_s} w_i a_{s,i} \quad (3)$$

Target

For each target unit of analysis, scores were added and averaged (i.e., Arithmetic Average Method) independently for Sensitivity and Exposure attributes. Because all target species interact with their fisheries, no 0 values are associated with these units of analysis. For target species with multiple Units of Analysis, Exposure and Sensitivity results were further averaged to provide an overall target-specific score. All attributes were assigned an equal weight w_i=1/A_e or w_i=1/A_s.

Bycatch

Bycatch units contained multiple groups (e.g., elasmobranchs, salmonids) for each target or Unit of Analysis; therefore, scores for each group were summed and averaged by axis, and those groups with 0 scores were removed from analysis. Average values among categories were then further summed ("Cumulative Method") to provide final scores for each target or unit of analysis. That is, after using Equation 1 to calculate risk R_b for each individual Bycatch group b, cumulative risk to all bycatch groups C_B was calculated as

$$C_B = \sum_{i=1}^{B} R_b \tag{4}$$

The Arithmetic Average Method (as described above for target analysis) does not incorporate sample size (i.e., number of groups that interact with the fishery) and gives all groups in the fishery equal weight. By contrast, target and target/fisheries units interacting with more bycatch groups score higher using the Cumulative Method. The Cumulative Method also gives greater emphasis to groups that score relatively high and are therefore more likely to be heavily affected by the fishery.

Bycatch attributes were weighted to reflect their relative importance. One Sensitivity attribute (Release Mortality) and one Exposure attribute (Magnitude) were weighted to represent 50% of the total score for each axis. That is, $w_{magnitude}$ = 0.5 and w_i = 0.5/(A_e-1) for the other exposure attributes, while $w_{release\ mortality}$ = 0.5 and w_i = 0.5/(A_s-1) for the other sensitivity attributes. This decision was made based primarily on the feedback of stakeholders and CDFW, who felt that these attributes were the main drivers of each category and provided results that better matched their understanding of how fisheries impacted bycatch. The relative weighting of bycatch attributes can be further modified as needed (for example, could choose to weight Release Mortality at 50%, Magnitude at 25%, or choose different attributes altogether).

Relative weighting was not implemented among bycatch groups because doing so would require a subjective value-judgment. Options exists for displaying the results that can highlight fisheries that interact with special status species or which interact with higher numbers of bycatch guilds (see Results Section XX) for examples of this.

Habitat

The Habitat focal component contained multiple groups (e.g., kelp, soft bottom) for each target or unit of analysis; therefore, (as with bycatch units) scores for each group were summed and averaged by axis. A Weighted Arithmetic Average Method was used to calculate final scores. This decision was made largely based on stakeholder feedback and can be modified as needed. Instead of utilizing the cumulative method, each fished habitat h was weighted by a factor w_h based on the relative amount of fishing effort. For example, if a fishery mostly interacts with estuaries (95%), and nominally with soft bottom (5%), the final score will be weighted using 95% of the estuaries score and weighted 5% with the soft bottom scores. That is, risk to all habitats R_H was calculated based on risk to individual habitats R_h (from Equation 1) as

$$R_H = \sum_{i=1}^{H} w_h R_h \tag{5}$$

Like bycatch attributes, habitat attributes were weighted to reflect their relative importance. One Sensitivity attribute (Potential Damage to Habitat from Gear Type) and one Exposure attribute (Gear Footprint) were weighted to represent 50% of the total score for all attributes on each axis. That is, $w_{gear\ footprint}$ = 0.5 and w_i = 0.5/(A_e-1) for the other exposure attributes, while w_{damage} = 0.5 and w_i = 0.5/(A_s-1) for the other sensitivity attributes. This decision was made based primarily on the feedback of CDFW and stakeholders, who also considered other options such as a gear multiplier and weighting of additional attributes. The weighting of habitat attributes can be further adapted as needed.

Image credit: Klaus Stiefel