External Review of California's Enhanced Status Reports for State-Managed Marine Fisheries

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A report to the Resource Legacy Fund

Terms of Reference

The Terms of Reference outlined the following five tasks:

A. Review the management sections of all 36 ESRs and extract how sustainability under the Marine Life Management Act (MLMA) is maintained.

This is provided in Sections 1 and 2 of this report.

B. Synthesize these results in an easy to understand table and summarize common approaches to defining overfishing.

This is provided in Sections 1 and 2 of this report. The table is featured in Table 1.

C. Work with RLF to identify a subset of 10-18 fisheries where providing California Department of Fish and Wildlife (CDFW) with well-supported management considerations would be most impactful.

This is featured in Appendix A of this report.

D. Develop recommendations for how CDFW should adjust its current approaches to management and data collection. Where appropriate, also include analysis and recommendations on how CDFW could transition to an approach based on overfishing thresholds.

This is featured in Section 3 of this report.

E. Document results in a technical report.

This report represents the submitted technical report.

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1. Introduction

The purpose of this report is two-fold. First, we provide a review of how sustainability reference points are defined and monitored for California's 37 harvested marine species with Enhanced Status Reports (ESRs). Second, we provide tactical advice on how to operationalize sustainability reference points in more of California's ESR fisheries. The management of fisheries using target reference points has been central to improving the sustainability and profitability of global fisheries (Hilborn et al., 2020; Melnychuk et al., 2021). Specifically, defining and tracking reference points allows managers to make rapid, transparent, and repeatable decisions about when and what interventions are needed to achieve fisheries objectives.

We consider both overfished and overfishing reference points. Overfished reference points are used to identify when a stock is in an overfished state. They are also commonly referred to as biomass reference points because they describe a level of biomass or abundance below which a population is considered to be overfished. Overfishing reference points are used to identify when a stock is experiencing levels of fishing that would ultimately cause the stock to become overfished. Thus, overfishing can occur before a population is overfished. Overfishing reference points are also called fishing mortality reference points because they describe a rate of fishing mortality above which a population would be considered to be experiencing overfishing.

Overfished and overfishing reference points are conceptually similar across global fisheries management systems though their operational definition is variable (Hilborn, 2020). California's Marine Life Management Act (MLMA), which became law on January 1, 1999, provides the legislative basis for defining overfished and overfishing reference points for California's fisheries.

The MLMA indicates that a population should be declared **overfished** if it is *"depressed, and the principle means for rebuilding the population is reduction of take"* (FGC §97.5). It defines a **depressed** population as a population where *"a declining population trend has occurred over a period of time appropriate to that fishery"* (FGC §90.7).

The MLMA indicates that a population is experiencing **overfishing** when it is experiencing a *"rate or level of taking that the best available scientific information, and other relevant information that the commission or department possesses or receives, indicates is not sustainable or that jeopardizes the capacity of a marine fishery to produce the maximum sustainable yield on a continuing basis*" (FGC §98).

The MLMA requires that every Fishery Management Plan (FMP) prepared by the California Department of Fish and Wildlife (CDFW) must:

1. *"Specify criteria for identifying when the fishery is overfished"* or experiencing overfishing (FGC §7086);

2. *“Contain measures to prevent, end, or otherwise appropriately address overfishing and to rebuild the fishery”* when a fishery is determined to be overfished or experiencing overfishing (FGC §7086);
3. *“Specify a time period for preventing or ending or otherwise appropriately addressing overfishing and rebuilding the fishery that shall be as short as possible, and shall not exceed 10 years except in cases where the biology of the population of fish or other environmental conditions dictate otherwise”* (FGC §7086)*;*
4. *“Allocate both overfishing restrictions and recovery benefits fairly and equitably among sectors of the fishery”* (FGC §7086).

However, these requirements do not apply to fisheries not managed with a formal FMP.

To understand how overfished and overfishing reference points are defined in California’s ESR fisheries, we reviewed *“Section 3.1.1.1. Criteria to identify when fisheries are overfished or subject to overfishing, and measures to rebuild”* of each ESR. We identified which fisheries are managed using defined overfished and overfishing reference points and summarized how those reference points work. This constitutes *Section 2* of this report.

We then reviewed the ESR’s of ten species spanning a diversity of taxa, sector types (commercial, recreational, both), and data availability (rich, moderate, poor) and provide recommendations for how to define and monitor sustainability reference points for these species. This constitutes *Section 3* of this report. The procedure for selecting these ten species is described in *Appendix A* of this report.

2. Current reference points

Overfished and overfishing reference points have only been defined for the five ESR species with formal Fisheries Management Plans (FMPs) (**Table 1**). None of these species have both overfished and overfishing reference points. Overfishing reference points, which are less data-intensive, have been specified for three species: pink shrimp (*Pandalus jordani*), white sea bass (*Atractoscion nobilis*), and market squid (*Doryteuthis opalescens*). Overfished reference points, which are more data-intensive, have been specified for California spiny lobster (*Panulirus interruptus*) and California sheephead (*Semicossyphus pulcher*). The methods used to define and monitor these reference points provide instructive examples for the incorporation of reference points into the management of other ESR species. We provide a brief overview of the reference points used in these five fisheries, with special attention paid to their data requirements. The species are presented from least data-intensive to most data-intensive.

2.1 Pink (ocean) shrimp

The Pink Shrimp FMP implements a harvest control rule (HCR) originally developed by the Oregon Department of Fish and Wildlife (ODFW) to identify and curb overfishing for Oregon pink shrimp. The harvest control rule uses both target and limit reference points. The target reference point is triggered if average landings per trip in June, three months into the fishing season, are below 12,500 lbs per trip. Landings below this threshold are believed to signal weak recruitment of one-year-old shrimp into the fishery. When this reference point is crossed, the season is scheduled to close two weeks early (October 15) and the following season is scheduled to start two weeks late (April 15). The limit reference point is specified as a dual trigger based on catch-per-unit-effort (CPUE, landings per trip) and environmental conditions (sea level height at the Crescent City tide gauge). This reference point is designed to signal when there are both poor adult stock conditions and poor larval retention and survival due to environmental conditions. Under such conditions, it is thought that continued fishing would impact reproduction and delay population rebound. Thus, when crossed, the fishery is closed following 10 days of public notice and the start of the following season is delayed two weeks (opening April 15) (**Figure 1**).

Effectiveness: The management of pink shrimp appears effective given the positive momentum towards Marine Stewardship Council (MSC) certification. The Pink Shrimp fishery first applied for MSC certification in 2015. During this review process, management was only disqualified from certification based on a low score for stakeholder engagement. As a result, CDFW took large efforts to improve pathways for stakeholder feedback on stock dynamics and management actions. The fishery re-applied for certification in 2023. The fishery received an improved score and MSC released a Public Comment Draft Report in January 2023 indicating that the fishery met all the criteria required to receive MSC certification. A final decision will be made soon.

Data requirements: The data requirements for monitoring these overfishing definitions are logbooks and sea level height measurements. Note that both have to be collected in near-real time since, under the dual limit trigger, they aim to close the fishery as soon as possible.

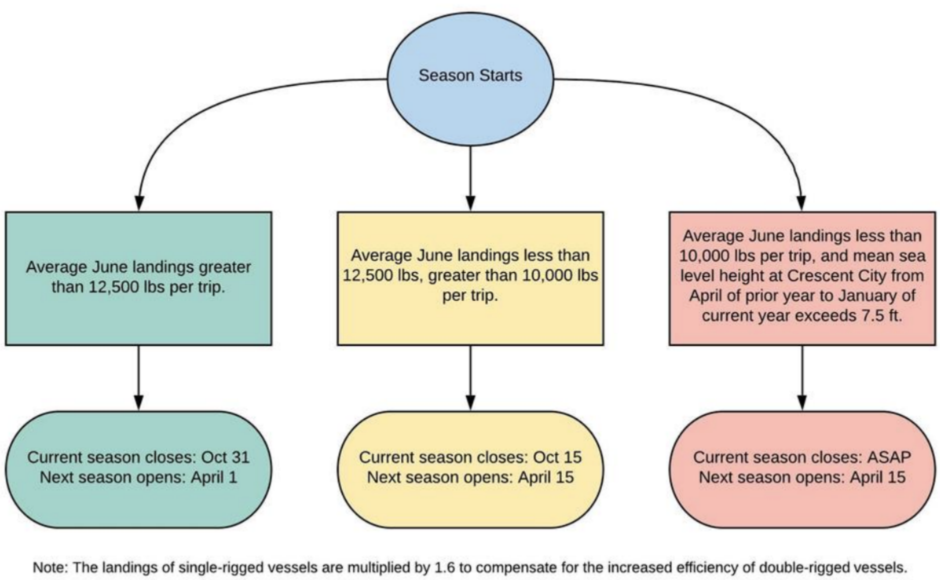


Figure 1. A conceptual schematic illustrating the harvest control rule used to manage pink shrimp. This figure is taken from the Pink Shrimp FMP.

2.2 White seabass

The White Seabass FMP identifies overfishing as occurring if any of the following quantitative criteria are met:

1. Total annual catch (commercial and recreational) exceeded or is expected to exceed the 1.2 million lb optimum yield;
2. Total annual commercial catch declined by ≥20% over the past two seasons relative to the prior five season average;
3. Total annual recreational catch declined by ≥20% in both number of fish and their average size;
4. Recruitment indices for juvenile white seabass derived from the Ocean Resources Enhancement and Hatchery Program (OREHP) declined by ≥30% relative to the prior five season average.

The White Seabass FMP also identifies overfishing as occurring if any of the following qualitative criteria are met:

1. New information on the status of white seabass is discovered.
2. An error in data or stock assessment is detected that significantly changes estimates of impacts due to current management.
3. Any adverse or significant change in the biological characteristics of white seabass (size composition, age at maturity, or recruitment) is discovered.
4. Any adverse or significant change in the availability of white seabass forage or in the status of a dependent species is discovered.

While qualitative criteria offer management flexibility, their subjectivity can also inject ambiguity into the decision making process and reduce predictability and transparency for fishermen.

CDFW is currently revisiting the "points of concern" framework for identifying whether overfishing is occurring through a FMP Review Process due to concerns that gradual, long-term declines may not be flagged by this framework given its narrow focus on the past two seasons (Huff McGonigal, personal communication). CDFW is also concerned that the size limit should be higher given new data that contrasts with the data from the >80-year-old maturity study that the current size limit is based on (Huff McGonigal, personal communication).

Effectiveness: An inspection of the historical commercial and recreational landings data reported in the ESR suggests that management measures have kept the annual harvest of white seabass well below the 1.2 million pound (544 metric ton or 600 short ton) harvest guideline. A 2016 stock assessment (Waterhouse and Valerio 2016) found that white seabass abundance has declined since the mid-2000s but that the 2015 biomass was above the MSY biomass reference point. However, CDFW continues to monitor the fishery closely, indicating effective adaptive management of this resource.

Data requirements: The data requirements for monitoring the quantitative overfishing definitions for white seabass are time series of: (1) total catch; (2) total commercial catch; (3) total recreational catch; (4) length composition of the recreational catch; and (4) recruitment indices. Many of these data types are available for many of the ESR species.

2.3 Market squid

The Market Squid FMP defines overfishing as occurring when, on average, females are caught before being able to spawn 30% or more of their lifetime egg production. This "egg escapement" method is rooted in "per recruit" population dynamics theory and the 30% escapement threshold was selected because it is believed to be the minimum amount of escapement necessary for the population to maintain abundance into the future. Although the egg escapement method was intended to be a temporary measure until squid biomass could be estimated, it has remained the prevailing strategy given the absence of improved methods. While the method is not used for real-time management, it is used to assess the effectiveness of past management measures.

Effectiveness: The effectiveness of California market squid reference points and management is challenging to evaluate given the boom-and-bust nature of market squid and the fact that the escapement reference points are not directly used to guide management. The latter means that it is difficult to clearly tie management actions (and their impacts on fisheries performance) to the escapement reference points.

Data requirements: The per-recruit model principally requires data on the fecundity of harvested females, which can either be directly obtained by counting the number of eggs in their reproductive tracts or indirectly estimated through the measurement of biometric proxies such as mantle thickness and gonad mass. From 2014 to 2020, 2.8% to 6.3% of female squid landings were sampled to assess mean catch fecundity.

2.4 California spiny lobster

The Lobster FMP defines biomass reference points linked to three fishery-dependent biomass indicators. These reference points are not strictly interpreted as indicating that the stock is "overfished" but as indicating that more investigation or caution might be needed. As a result, they do not necessarily trigger management intervention. The three indicators and triggers are:

1. **Catch:** The total catch in a fishing season is considered a proxy for stock size and is monitored as a ratio of the average catch in the three most recent seasons to the average catch in the 10 most recent seasons. Although catch may change for reasons besides population size (e.g., economic or regulatory reasons), significant changes in

catch signals a need for attention. Averaging catch serves to dampen normal interannual variability while still exposing long-term trends. Management action is considered, though not mandated, when this ratio drops to or below 0.9, indicating that current average catch is ≤90% of the decadal average. Because the averages dampen small gradual changes, drops in this ratio for six consecutive seasons will also trigger scrutiny.

2. **Catch-per-unit-effort (CPUE):** Catch-per-unit-effort, defined here as legal lobsters per trap pull and derived from logbook data, provides an index of relative abundance. As with catch, CPUE is monitored using the ratio of average catch in the most recent three seasons to the most recent ten seasons. Management action is also considered, but not mandated, when this ratio falls to or below 0.9 or when it declines for six consecutive seasons. Interestingly, retrospective analysis of these two indicators show that they are not triggered in the same seasons, which means they capture different signals. Whether this is a virtue or a challenge likely deserves more attention.
3. **Spawning potential ratio (SPR):** The spawning potential ratio represents the ratio of eggs produced by the current population relative to its unfished potential. It ranges from one when the population is unfished to zero when the population is extinct. Estimating SPR requires information on the size or age structure of the stock in addition to estimates of growth, natural mortality, maturity, and fecundity. Management action is considered, but not mandated, when SPR falls below the average SPR of the 2000-01 to 2007-08 seasons, which CDFW deems as stable and productive. Of the three indicators, SPR contains the most biological information and is the best indicator of recruitment overfishing, but it is also the most data intensive and expensive to monitor.

<u>Effectiveness:</u> The fishery appears to be performing well by a number of measures: (1) commercial participation has been stable since 2000 and recreational participation has been stable since at least 2014 (the first year that recreational lobster cards were required to be submitted); (2) commercial landings have remained relatively stable since the 1990s; (3) commercial revenues have increased steadily since the 1980s; and (4) a 2011 stock assessment suggests that stock abundance was stable from 1980-2011 (Neilson, 2011) and CPUE since 2011 has remained stable with an uptick in recent years (CDFW, 2024).

<u>Data requirements:</u> The data requirements are as follows for each indicator: (1) catch – total catch from landing receipts; (2) CPUE – catch and effort from logbooks; (3) spawning potential ratio – length composition from port sampling and estimates of key life history parameters.

2.5 California sheephead

California sheephead are managed as part of the Nearshore FMP, which outlines a hierarchical approach to defining fisheries sustainability reference points, based on the level of Essential Fishery Information (EFI) available. These three “Stages” are summarized below:

- **Stage 1 (data-poor):** Stocks in Stage 1 generally only have information on the catch history and catch limits are set as a fraction of the average catch from a series of years where abundance was thought to be stable (i.e., not declining). In the absence of information to the contrary, the fraction is set at 50%.
- **Stage 2 (data-moderate):** Stocks in Stage 2 have sufficient information to support a stock assessment capable of estimating biomass and fishing mortality reference points, which are subsequently used to support a 60-20 harvest control rule. Under this harvest control rule, when a stock is at or above 60% of its unfished biomass (B_0), it is considered "healthy" and is fished at the default ($F_{50\%}$) fishing rate. When below 60%, it is in the "precautionary" zone and the fishing mortality rate must be linearly decreased from $F_{50\%}$ at 60% of B_0 to zero at 20% of B_0. A stock is considered overfished when biomass is estimated to be below 30% of B_0.
- **Stage 3 (data-rich):** Stocks in Stage 3 have sufficient information to support full ecosystem-based management, which involves Stage 2 management plus the incorporation of marine reserves and other environmental factors.

California sheephead is considered Stage 1 and catch limits were determined in 2002 by reducing average total (recreational and commercial) catch from 1983-89 and 1993-99, two periods when population size was thought to be stable and when both commercial and recreational catch data were both available, by the default 50%. This resulted in a total allowable catch (TAC) of 205,500 pounds, of which 75,200 (36%) and 130,300 (64%) pounds are allocated to the commercial and recreational fisheries, respectively.

<u>Effectiveness:</u> The ESR asserts that: "there is no apparent need for management change for sheephead at this time, as populations appear to benefit from MPAs, catch is managed through a TAC, and landings appear to be stable." However, inspection of the commercial catch data in the ESR suggests that the commercial TAC has been exceeded in 8 years since being established in 2002: 2002-2006, 2008, 2014-2015. Similarly, inspection of the recreational catch data in the ESR suggests that recreational TAC has been exceeded in 5 years since 2002: 2002, 2003, 2013, 2020, and 2021. Collectively, this suggests that management measures have not been effective at controlling catch within the specifications of the FMP.

<u>Data requirements:</u> Stage 1 requires only a time series of catch. At minimum, Stage 2 management requires a time series of catch and an index of relative abundance.

Table 1. Fisheries sustainability reference points, stock assessments, fisheries management plans (FMPs), and management strategy evaluation models (MSEs) for the 37 Enhanced Status Report (ESR) species. * indicates academic stock assessments

Common name	Overfished reference points	Overfishing reference points	Last stock assessment	FMP	MSE
Barred sand bass	None	None	None	None	Valencia et al. 2021*
Barred surfperch and redtail surfperch	None	None	None	None	Valencia et al. 2021*
Brown smoothhound shark	None	None	None	None	None
California corbina	None	None	None	None	None
California grunion	None	None	None	None	None
California halibut	None	None	None	None	Valencia et al. 2021*
California sheephead	B0	None	2004 (Alonzo et al 2004)	Nearshore	None
California spiny lobster	Catch, CPUE, SPR	None	2011 (Neilson 2011)	CA Spiny Lobster	Valencia et al. 2021*
Dungeness crab	None	None	2020* (Richerson et al. 2020)	None	None
Giant kelp and bull kelp	None	None	None	In progress	None
Giant red sea cucumber	None	None	None	None	None
Jacksmelt	None	None	None	None	None
Kellet's whelk	None	None	None	None	None
Kelp bass	None	None	None	None	Valencia et al. 2021*
Market squid	None	Egg escapement, landings	None	Market Squid	None
Night smelt	None	None	None	None	None
Ocean pink shrimp	None	Landings	None	Pink (Ocean) Shrimp	None
Ocean whitefish	None	None	None	None	None
Pacific angel shark	None	None	None	None	None
Pacific barracuda	None	None	None	None	None
Pacific bonito	None	None	None	None	None
Pacific geoduck clam	None	None	None	None	None
Pacific hagfish	None	None	None	None	None
Pismo clam	None	None	None	None	None
Red sea urchin	None	None	None	None	Valencia et al. 2021*
Ridgeback prawn	None	None	None	None	None
Rock crabs	None	None	None	None	Valencia et al. 2021*
Shiner perch	None	None	None	None	None
Spot prawn	None	None	None	None	None
Spotted sand bass	None	None	None	None	None
Surf smelt	None	None	None	None	None
Warty sea cucumber	None	None	In prep (length-at-age model)	None	Valencia et al. 2021*
White croaker	None	None	None	None	None
White seabass	None	Landings	2016 (Valero & Waterhouse 2016)	White Seabass	None
White sturgeon	None	None	2019* (Blackburn et al. 2019)	None	None

Yellowfin croaker	None	None	None	None	None
Yellowtail	None	None	None	None	None

3. Detailed ESR reviews

In the following section, we review the ESR's of ten species spanning a diversity of taxa, sector types (commercial, recreational, both), and data availability (rich, moderate, poor) and provide recommendations for how to define and monitor sustainability reference points for these species. See *Appendix A* for details on how these species were selected.

3.1 Dungeness crab

3.1.1 Current management

Dungeness crab (*Metacarcinus magister*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting Dungeness crab.

Action	Recreational	Commercial
Catch	Daily bag limit	*No limits*
Effort	*Open access*	Restricted access
Gear	Design criteria	Design criteria
Time	Seasons	Seasons
Sex	*No limits*	Only male crabs
Size	>5.75"	>6.25"
Area	*North of Pt. Arguello*	Not allowed in Eel River, Trinidad Bay, Humboldt Bay, Bodega Harbor, and Crescent City Harbor

However, there are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"There is no current reference point to specify a level of fishing effort or harvest that would be considered overfishing, or to specify a level of biomass which would be considered overfished. There are no current regulations in place to halt overfishing, or to rebuild populations when they fall below biomass thresholds… The Department will monitor trends in catch and effort and if concerns should arise will consult with stakeholders on any recommended actions."*

This text suggests that CDFW monitors trends in catch and effort and will consider adjusting management in response to this information. However, the text lacks necessary specifics about how indicators are calculated, evaluated, and responded to when exceeded.

We discuss a few approaches for setting reference limits in the Dungeness crab fishery by drawing from the approach used for Dungeness crab in Oregon. We also discuss how the annual update of the Richereson et al. (2020) depletion model could be used to track fishing exploitation rates in the Dungeness crab fishery.

3.1.2 Reference points based on landings and CPUE indicators

The Oregon Department of Fish and Wildlife (ODFW) uses reference points in the management of Oregon Dungeness crab, which provides an instructive example for California to consider.

Specifically, ODFW will adjust management of Dungeness crab when a Limit Reference Point (LRP), presumed to indicate an undesirable state that management should try to avoid, is reached. ODFW evaluates the limit reference point within eight weeks of the season opener and consider the LRP to have been reached when all of the following conditions are met:

1. Landings have declined for three consecutive seasons;
2. Landings are projected to decline for a fourth consecutive season based on early season landings in the fourth (current) season;
3. Landings in the fourth (current) season of a decline are projected to fall below 20% of the 20 year average based on early season landings; and
4. Logbook catch-per-unit-effort falls below the average level predicted to have occurred over the 1980-81 through 1986-87 reference seasons.

California is already poised to implement the first three criteria of this Limit Reference Point framework. However, it would need to initiate a commercial logbook program for Dungeness crab to parameterize and monitor the last indicator. Alternatively, catch-per-unit-effort could be calculated using the fish ticket data where each fish ticket is assumed to represent a “fishing trip.” While this is an oversimplification (a single fish ticket could reflect multiple trips or even just part of a trip), Richerson et al. (2020) had success with this assumption in the California Dungeness crab fishery after validating it in Oregon and Washington, where fishermen submit logbooks in addition to fish tickets. The implementation of logbooks in the Dungeness crab fleet could also help to improve management of whale entanglements in the fishery as effective management is empowered by an improved understanding of where fishing effort occurs. E-logbooks would be especially helpful because they automatically log accurate spatial information on where traps are deployed and share this information immediately. Furthermore, they improve the quality of entered data by imposing built-in entry standards.

The Oregon Dungeness Crab Research and Monitoring Plan provides a menu of adaptive management actions that managers can select from when the Limit Reference Point is met (ODFW, 2014), including season closure, pot limit reductions, trip limits, area closures, and increases in the minimum size limit. California is well-poised to establish a similar menu of actions as all but trip limits are currently used in California Dungeness crab management and similar measures exist within the formal California Lobster Fishery Management Plan.

3.1.3 Depletion of legal-sized males crabs

The derby nature of the California Dungeness crab fishery allows the estimation of pre-season abundance through depletion models. Depletion models extrapolate population size by assuming a linear relationship between catch-per-unit-effort and the cumulative catch so that the cumulative catch where catch-per-unit effort equals zero represents the population size (Richerson et al., 2020).

Estimates of pre-season legal-sized male biomass could be used to set fixed escapement targets. For example, managers could set a target reference point for 10% of legal-sized males to escape harvest each year and be allowed to spawn. In this scenario, a catch limit of 90% of the estimated pre-season legal-sized male biomass would be set. Managers could then assess past or current landings against the relevant catch limit. Thus, management could be triggered in season when catch exceeds the catch limit or could be applied to the current season when the past season is assessed to have exceeded the catch limit (*sensu* an accountability measure).

Richerson et al. (2020) developed a Bayesian depletion model for West Coast Dungeness crab that could be turned into an R package for repeated tactical use. **Figure 1** illustrates estimates of pre-season legal sized male abundance in the four regions evaluated.

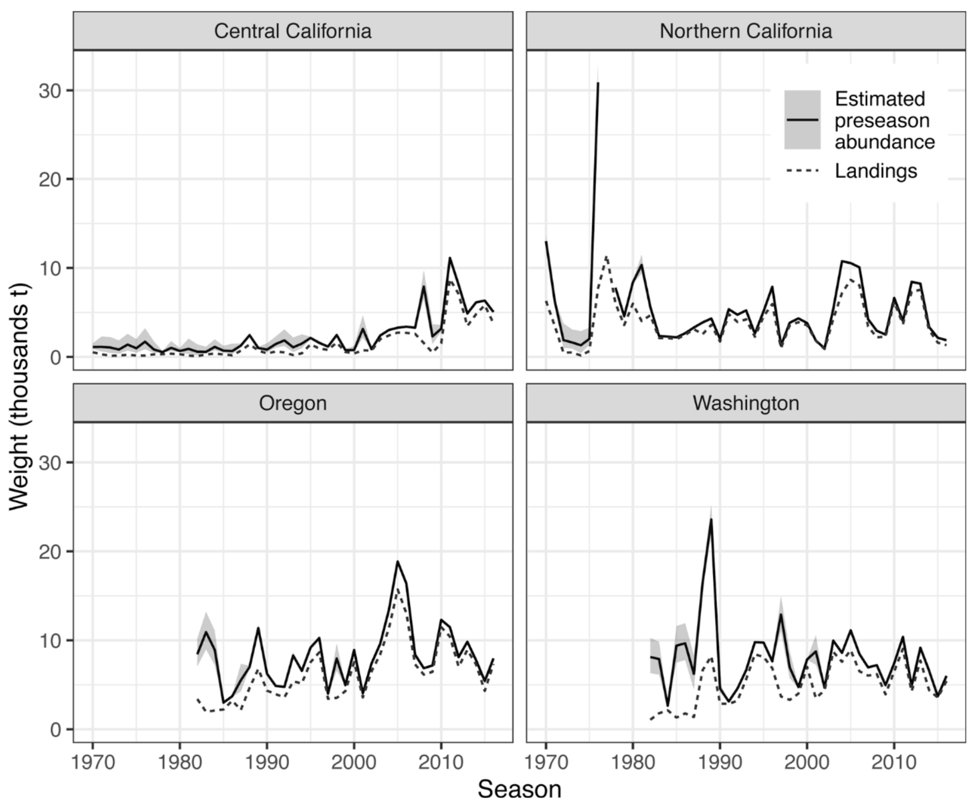


Figure 1. Estimated pre-season abundance of legal-sized male Dungeness crabs on the West Coast from the Richerson et al. (2020) depletion model.

3.1.4 Recommendations

We favor the idea of managing the California Dungeness crab fishery using the Oregon Limit Reference Point framework over the escapement threshold framework for several reasons. First, California is immediately poised to implement such a system, whereas the escapement threshold framework would require the development of new tools. Second, an escapement threshold could imperil the spring fishery, which supports small boats that specialize in Dungeness crab and fish for it throughout the season (Liu et al., 2023). Third, the fishery is likely to be more constrained that it has been historically given rising closures due to whale entanglement and harmful algal blooms (**Figure 2**). In fact, in establishing a Limit Reference Point system, managers will need to account for reductions in landings that happen because of management (closures, depth restrictions, gear restrictions) as opposed to population dynamics. The value of adopting a Limit Reference Point framework will be especially clear if Oregon successfully gets Marine Stewardship Council certification, which it is currently pursuing (White, 2018). MSC certification could bring premium prices and more competitive products.

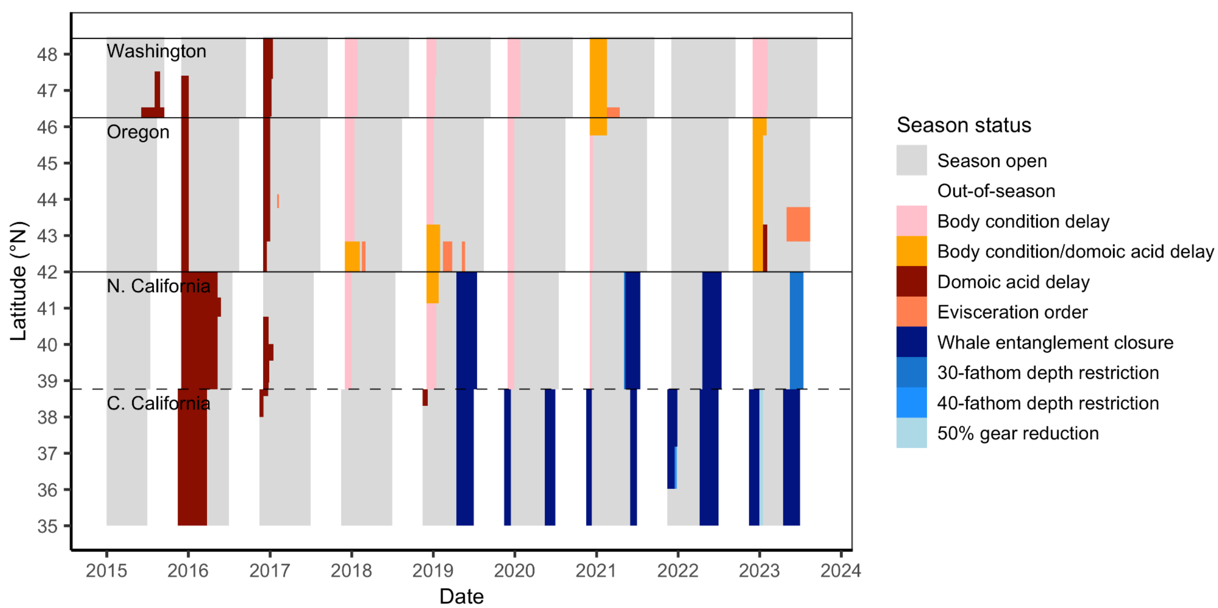


Figure 2. Spatial-temporal history of management actions in the West Coast Dungeness crab fishery. Adapted from (Free et al., 2022).

3.2 Warty sea cucumber

3.2.1 Current management

Warty sea cucumber (*Apostichopus parvimensis*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting warty sea cucumber.

Action	Commercial dive	Recreational
Catch	*No limits*	*No limits*
Effort	Limited entry	*Open access*
Gear	*No rules*	*No rules*
Time	Mar 1-Jun 14 closure	*None*
Sex	*No limits*	*No limits*
Size	*No limits*	*No limits*
Area	*No limits*	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"**Currently there are no formal overfishing targets or limits established for the warty sea cucumber dive fishery.** However, the Department closely monitors various fishery-dependent and fishery-independent data streams to assess the condition of the fishery, as well as to monitor unfished populations within MPAs which provide an indication of natural population trends. Commercial landings data provide valuable information related to landings and value (i.e. price per lb) for a given unit area (e.g. commercial fishing block), with commercial dive log data providing valuable information about the fishing activities resulting in these landings. **Sudden or drastic decreases in landings and/or CPUE, combined with increasing value may provide an indication that the abundance of the resource is in decline and/or potentially overfished.** Fishery-independent survey data of warty sea cucumber populations within MPAs and outside fished areas provide critical information related to changes in natural populations that can be used to inform the degree to which natural variation may account for changes in populations versus changes that may be related to fishing. The continued monitoring of densities within MPAs and outside fished areas may be used to adaptively manage this resource in the future. For example, **this monitoring may be used to determine the extent of management intervention needed to rebuild an overfished stock, as well as to monitor the level of recovery exhibited by the resource in response to management measures.** Additionally, the sustainability of the fishery is*

> *currently being evaluated through various methods, including length-at-age-based models and the Data Limited Methods Toolkit to conduct a Management Strategy Evaluation (MSE) of alternative management procedures."*

This text suggests that CDFW monitors multiple data streams to determine whether management interventions are necessary and highlights good approaches for interpreting and responding to these indicators. However, the text lacks necessary specifics about how indicators are calculated, evaluated, and responded to when exceeded.

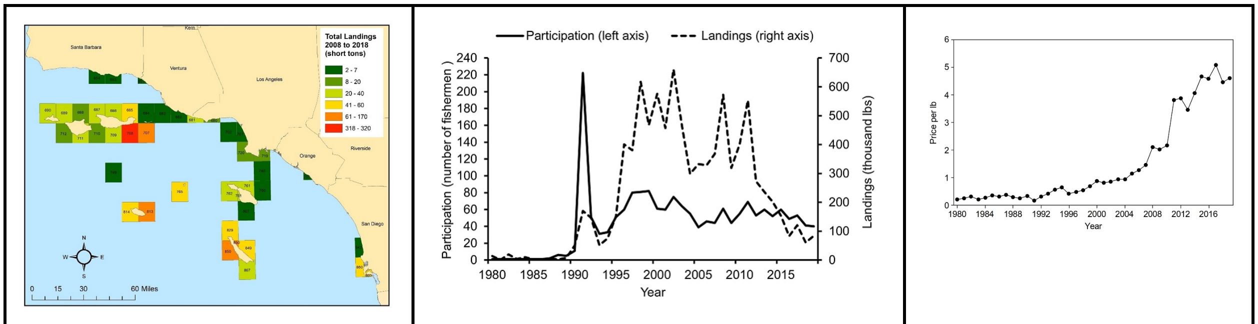
We discuss the potential for each of the indicators named in *Section 3.1.1.1* to be used to establish reference points and then discuss insights on appropriate management actions resulting from the management strategy evaluation for the species (Valencia et al., 2021).

3.2.2 Catch-per-unit-effort (CPUE)

The vast majority of warty sea cucumber catch comes from the commercial dive fishery. Recreational take of warty sea cucumber from diving is thought to be extremely limited and trawl take, while allowed, is limited due to the shallow nature of the species and strict limitations on when and where trawlers can operate in shallow waters. As a result, the vast majority of fishing effort for warty sea cucumber is recorded in commercial dive fishing logs. These logs record information on the amount (pounds) of sea cucumber harvested and the effort associated with this catch (number of dive hours). This means that a fishery-dependent catch-per-unit-effort (CPUE) index (e.g., pounds per diver hour) could be calculated and used to derive reference points for management. In fact, *Section 4.2.1. Fishery-dependent Data Collection* says that CDFW calculates and tracks such CPUE information, but the data are not visualized in the ESR.

However, the operational use of reference points based on a fishery-dependent CPUE index will critically depend on reconstructing catch to account for the condition (whole versus cut weight) of the sea cucumber catch recorded in commercial logbooks. Cut weights, which are reported when sea cucumbers are eviscerated or otherwise processed at sea, can be as much as 50% of whole weights. Thus, the conversion of all weights to either cut or whole weights is necessary to generate a reliable and unbiased index of relative abundance.

A quick inspection of the landings, effort, and price time series provided in the ESR (**Figure 1**) suggests that average CPUE from 1990-1995 might serve as a useful reference point. This period represents a time before price and landings spiked due to international demand as well as a period when landings and participation were substantive. These years also reflect a period of moderate relative abundance in the scientific survey data shown below (**Figure 2**).



A. Location of catch | B. Participation and landings | C. Price (USD/lb)

Figure 1. The **(A)** location of recent landings; **(B)** landings and participation in the fishery over time; and **(C)** ex-vessel price (USD per pound) over time.

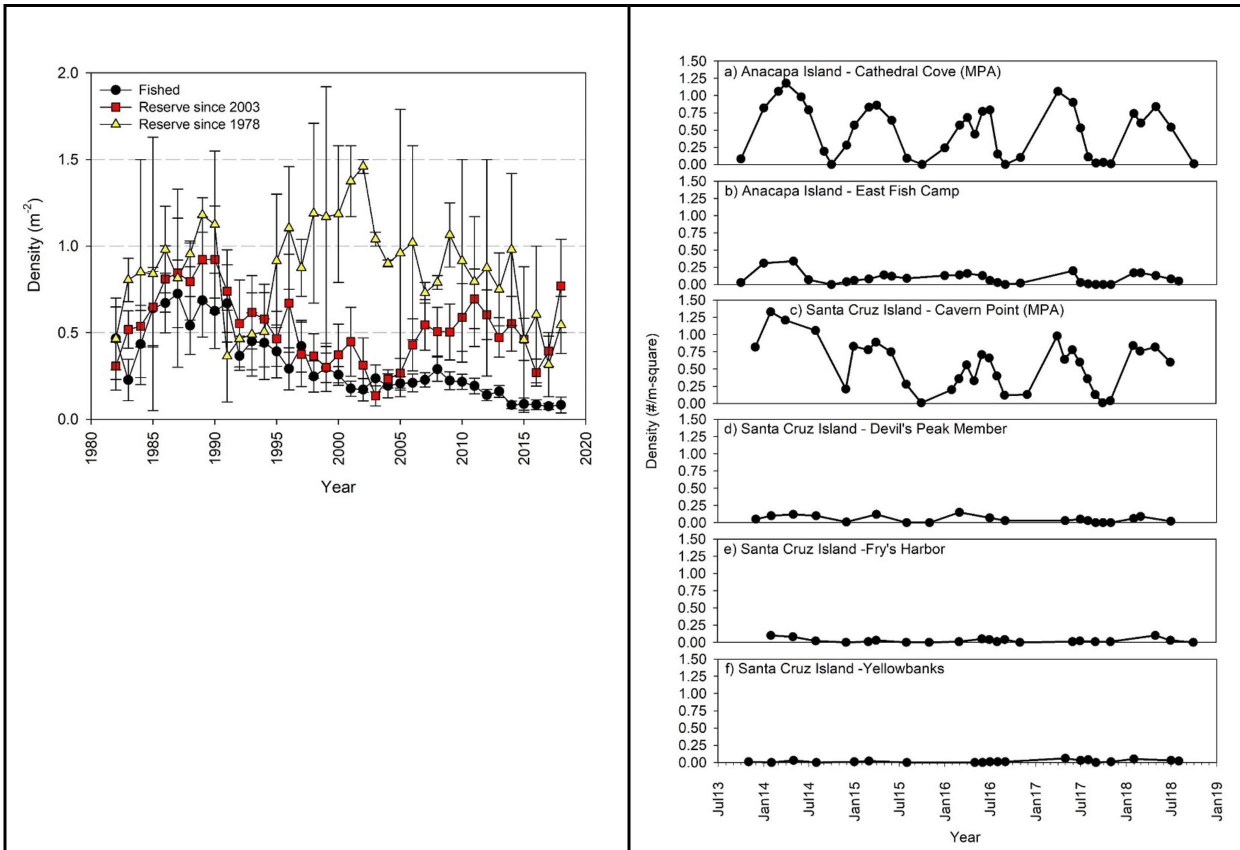
3.2.3 Indices of relative abundance

The National Park Service (NPS) Kelp Forest Monitoring Program (KFMP) has been monitoring the size and density of many fish, invertebrates, and algae, including warty sea cucumbers, at 17 marine protected area (MPA) sites and 19 fished sites around the northern Channel Islands since the early 1980s. The data from this program could provide the basis for the development of multiple types of fisheries reference points.

Empirical reference points: These scientific survey data could facilitate the development of an empirical reference point that triggers management when survey density falls below a pre-specified value. This is similar, for example, to how sea cucumbers are managed throughout Canada, where the highest value observed in the index of relative abundance is assumed to be a proxy for unfished biomass (B_0), 40% of that value is used as a proxy for B_{MSY} (the target reference point), and 20% of the B_0 proxy is used as the limit reference point (DFO, 2021).

Marine Protected Area density ratio-based reference points: Because the KFMP monitors sea cucumber densities in both fished and non-fished areas (MPAs), reference points could also be specified as ratios of relative abundance in the fished area relative to the non-fished area. This represents a depletion-based reference point. This type of reference point is advantageous because it accounts for the non-stationarity in population dynamics that result from fluctuating oceanographic conditions by being measured using a reference non-fished area experiencing the same environmental conditions. However, it is disadvantageous because the non-fished area must be comparable in its habitat quality to the fished area to be a useful reference site; otherwise, differences in density may be explained by habitat more than fishing. This is challenging as protected areas are often placed in areas with higher habitat suitability. The use of this approach to setting reference points would require careful validation of the reference site to ensure that it has comparable depth, wave exposure, bottom cover, vegetative cover, etc.

Additional considerations: In selecting an appropriate reference point, managers will have to consider seasonality, as warty sea cucumber abundance is known to be cyclical throughout the year. This is evident in the two unfished MPA sites illustrated in **Figure 2** below. Thus, it will be critical to either (1) calculate a model-based standardized index of relative abundance or (2) to generate the index using monitoring data collected at the same time of the year.



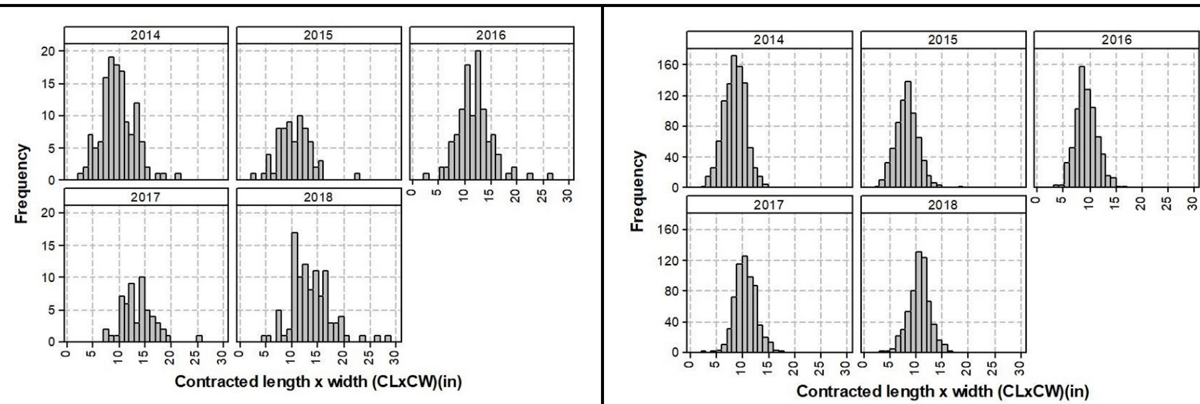
A. Annual abundance index	**B.** Sub-annual abundance index

Figure 2. The **(A)** relative abundance of warty sea cucumbers at two MPA sites and across all fished sites over time and **(B)** the relative abundance at sub-annual scales at six sites over time.

3.2.4 Length-based spawning potential ratio

The availability of size data from both fished and unfished areas makes length-based assessment approaches tempting but they may not be advisable. It is notoriously difficult to measure the length of sea cucumbers and it is not clear that the length proxies developed for sea cucumbers would meet the assumptions required for length-based spawning potential ratio (SPR) analyses (Hordyk et al., 2015). However, this could be a ripe space for research.

We also advise against the use of a length-based SPR analysis for this species because the available size structure information shows surprising patterns (**Figure 3**). The size structures from the fished areas show truncation at lower sizes rather than at higher sizes, which is atypical since fisheries normally select for larger sizes. This is the case for the warty sea cucumber fishery where processors ask fishermen to only harvest individuals larger than 1/3 lb (151 g) after removing water and viscera. This surprising truncation could be indicative of poorer recruitment in the fished areas than in the non-fished areas, which highlights a potential challenge in using reference points based on a Marine Protected Area (MPA) density ratio (see the text above for an explanation for why this methods depends on the reference site being similar to the MPA site to be a useful counterfactual).



A. Fished site size structure.	**B.** Non-fished site size structure.

Figure 3. The size structure of warty sea cucumbers in **(A)** fished and **(B)** non-fished areas.

3.2.5 Management strategies

The management strategy evaluation (MSE) of management procedures for warty sea cucumber provides useful insights into the management options that could be considered if the fishery were to exceed an established reference point (Valencia et al., 2021).

Management procedures related to size limits and effort reductions were found to maximize both long-term yield and biomass, while meeting the thresholds established for conservation performance, feasibility of governance and enforcement, and uncertainties related to various biological and fishery parameters. Findings suggest that a minimum size limit based on a cut body weight (internal viscera removed) that ranges from 130 to 150 grams (estimated weights at 90 to 95% sexual maturity) will best meet long-term conservation objectives. However, this is effectively already the practice, so this management procedure would not change the current status quo. As an alternative, effort reductions to 30-40% of current fishing effort performed well, but were less effective in meeting long-term conservation goals compared to size limits. Furthermore, effort has been reduced since 2018 as a result of a seasonal closure to protect spawning aggregations and further effort reductions could limit fishing opportunities.

Harvest control rules that adjust catch limits based on an index of abundance could be used to adaptively manage the fishery. Given that warty sea cucumbers appear to be negatively impacted by extended warm water periods, this approach could benefit the long-term sustainability of the stock by adjusting harvest in response to environmental conditions. Furthermore, catch limits protect against potential surges in demand, such as those experienced in 2011, which likely contributed to the current low stock status of the fishery. Thus, we recommend the development of empirical harvest control rules that are pegged to the index of relative abundance developed from the KFMP monitoring program.

3.2.6 Recommendations

We recommend the use of an empirical harvest control rule pegged to the index of relative abundance developed by the KFMP monitoring program. This is preferable to using a catch-per-unit-effort (CPUE) index developed from the logbook data because the KFMP index (1) extends further back in time; (2) is collected via scientific sampling; and (3) does not face the same cut versus whole weight problem. We recommend this approach over the length-based approach given the challenges in measuring length and the unusual length dynamics present in the existing data. Finally, such an approach is naturally adaptive to changing oceanographic conditions and was found to perform well in the MSE (Valencia et al., 2021). Managing the fishery using limit reference points is highly worthwhile given the known ability for international markets to incentivize the serial depletion of local cucumber stocks (Anderson et al., 2010) and the reality that California sea cucumbers are likely in low stock status due to such pressures.

3.3 Spot prawn

3.3.1 Current management

Spot prawn (*Pandalus platyceros*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting spot prawn.

Action	Commercial trap	Recreational
Catch	Fixed annual limit for Tier-2 vessels	Daily bag limit
Effort	Limited entry; trap limits	*Open access*
Gear	*Gear specifications*	*No rules*
Time	North: May 1-Jul 31 closure South: Nov 1-Jan 31 closure	*No limits*
Sex	*No limits*	*No limits*
Size	*No limits*	*No limits*
Area	Depth restrictions in south	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"Currently, there is no direct reference point for determining whether the stock is overfished, nor are there procedures in place specific to the spot prawn fishery to halt overfishing should that occur. However, yields per unit area (e.g., fishing block) and trends in overall landings represent indicators of exploitation. The yield of spot prawn per unit area may reflect changes in the spatial distribution of fishing that can be indicative of trends in spot prawn abundance. Moreover, long term increases or decreases in landings may provide an indication of whether or not populations of spot prawn are being overfished. This indicator has been used in the past to drive and inform management action (see section 3.1). The Department will monitor these indicators and will work with stakeholders and the Commission should concerns arise."*

We provide a summary of how CDFW has adjusted management in response to trends in catch and then discuss how trends in catch-per-unit-area, catch-per-unit-effort, and spawners-per-unit- effort could also be used to establish reference points for the spot prawn fishery.

3.3.2 Catch

In coordination with fishermen, CDFW has adjusted the management of the spot prawn fishery in response to trends in landings on several occasions over the past few decades (**Figure 1**). In 1984, in response to declining landings, CDFW implemented a seasonal closure for the trawl fishery from November to January between Point Conception and Point Mugu. This led to a temporary recovery in landings, but following a decline in catch in the 1990s, the closure was extended to include all of the southern California Bight in 1994. In 1994, managers also established the first restrictions for the trap fishery, including a November to January closure south of Point Arguello, trap limits of 500 traps per vessel, and minimum mesh sizes. Landings declined again in 1999, leading to an expanded trawl closure in 2000. The trawl fishery was ultimately closed in 2003 due to concerns over bycatch and impacts on hard bottom habitat.

Landings of spot prawn increased 2-4 years after each intervention, indicating that triggering interventions based on declines in catch may have been an effective strategy in the past.

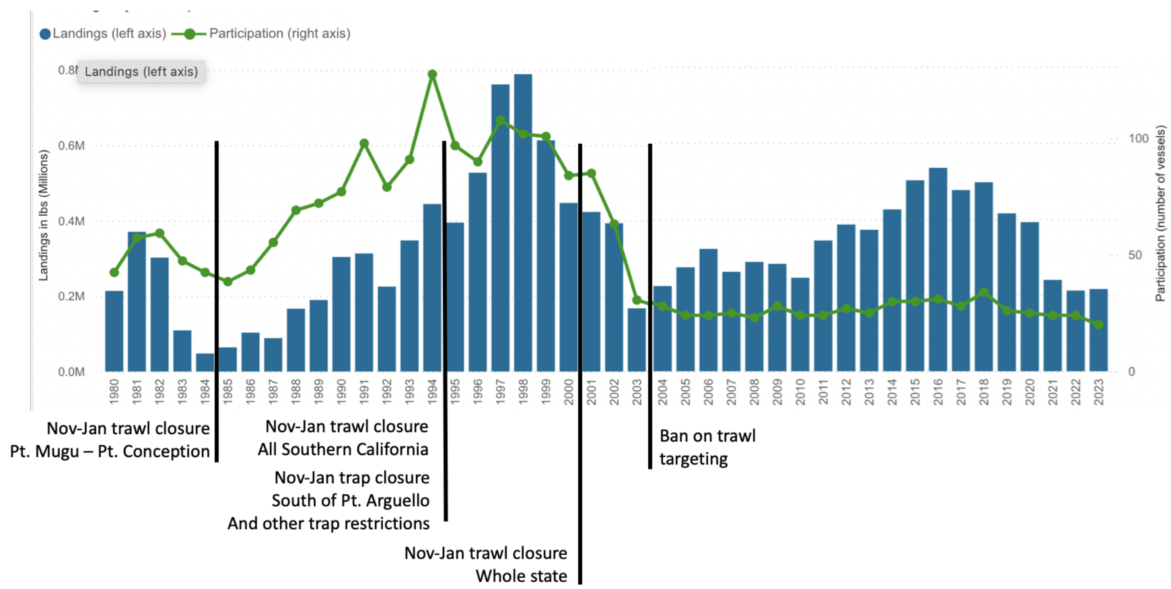
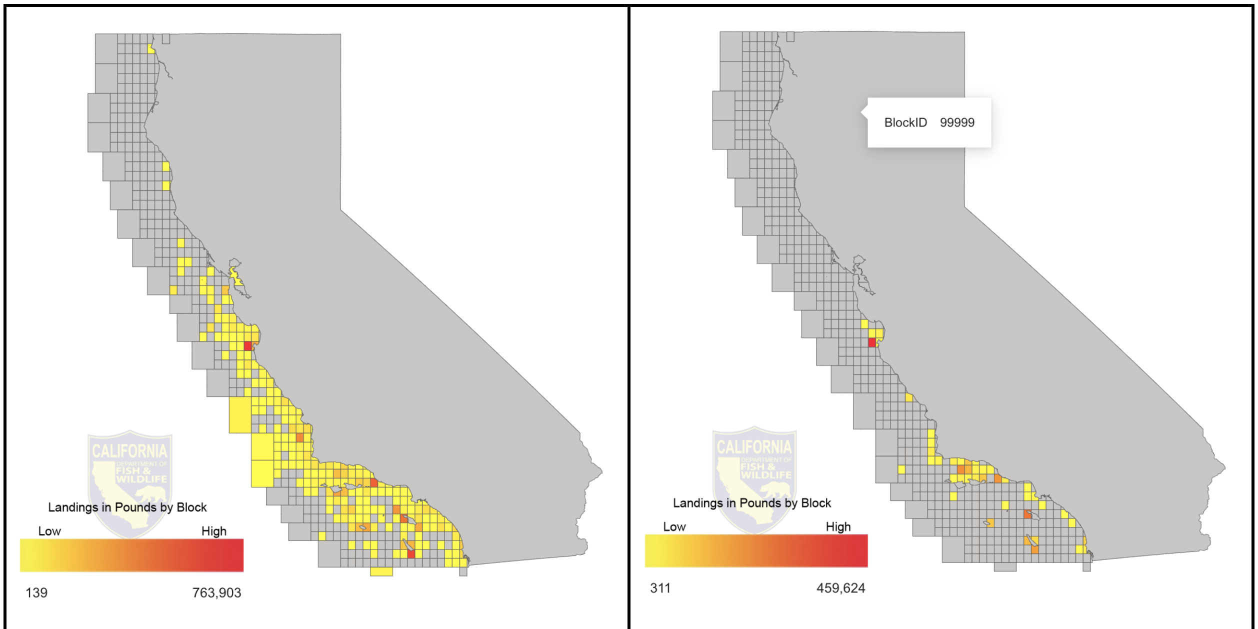


Figure 1. Landings and participation in the spot prawn fishery over time. The timing of management interventions is marked by vertical black lines. Figure adapted from the ESR.

3.3.3 Catch-per-unit-area

In *Section 3.1.1.1* of the ESR, CDFW reports that yields-per-unit-area could provide an index of relative abundance that could be used to specify reference points. Currently, these would have to be calculated from fish tickets, which report the amount and location (statistical reporting block) of spot prawn harvests. To reduce management complexity, instead of developing block-specific indices of relative abundance, managers should consider grouping blocks into regions defined by similar productivity regimes and developing abundance indices and reference points for those regions. **Figure 2** shows that the spot prawn fishery has operated within a much smaller footprint in the last decade (2013-present) relative to the decades before.



A. 1980-present landings by block	**B.** 2013-present landings by block

Figure 2. Total spot prawn landings by block from (A) 1980-present and (B) 2013-present.

However, yield-per-unit-area may reflect fishing effort more than productivity and abundance, which risks spuriously high reference points in places experiencing heavy fishing and spuriously low reference points in places experiencing light fishing. For this reason, it would be better to standardize for effort by standardizing to a "fishing trip", which could be assumed to be reflective of a single fish ticket. While this is an oversimplification (a single fish ticket could reflect multiple trips or even just part of a trip), Richerson et al. (2020) had success with this assumption in the California Dungeness crab fishery after validating it in Oregon and Washington, where fishermen submit logbooks in addition to fish tickets. This approach could be a useful intermediate while data are collected to support the more sophisticated approaches described below.

3.3.4 Catch-per-unit-effort

The implementation of mandatory logbooks in the spot prawn trap fishery could empower the calculation of a more accurate fishery-dependent catch-per-unit-effort index than can be calculated using fish tickets. This is because logbooks can more precisely document fishing effort by recording the number of traps and soak times associated with a fishing trip. Fish tickets contain much less information, as catch can be held over several trips before being sold (i.e., the ticket covers more than one trip) or sold to multiple first-buyers (i.e., the ticket covers less than a full trip). Currently, logbooks are submitted voluntarily but the amount and quality of these data are not, to our knowledge, summarized in publicly available documents.

Currently, prawn fisheries in Queensland, Australia are managed using reference points pegged to a standardized catch-per-unit-effort (CPUE) index. Specifically, management reviews are triggered when CPUE falls below 70% of the average CPUE observed from 1988 to 1997

(O'Neill, 2005). A similar method could be used in California but would require many years of logbook data to parameterize. The value of logbooks would increase if bycatch of protected species increases in the fishery, as has happened in the Dungeness crab fishery (Free et al., 2023). A detailed understanding of where fishing occurs and how many traps are deployed is critical in bycatch management and can be greatly improved with logbook information. E-logbooks would be especially helpful because they automatically log accurate spatial information on where traps are deployed and share this information immediately. Furthermore, they improve the quality of entered data by imposing built-in entry standards.

3.3.5 Spawner abundance indices and fixed escapement control rules

The management of Canadian spot prawn fisheries is done using a fixed escapement approach (Boutillier & Bond, 2000) that could be implemented in California with the initiation of an onboard or port-based sampling program to measure the sex and age composition of the catch.

The approach tracks the relative abundance of female spawners (i.e., spawners per trap night) and closes the fishery when a predefined reference point is exceeded, ensuring that a certain number of female spawners are present at the time of egg hatch. This approach relies on data from an in-season, industry-funded monitoring program: at-sea observers sample the catch and these data are used to estimate female spawner abundance indices and the sex and cohort composition of the catch on a per trap basis (Boutillier & Bond, 2000).

In California, it is possible that a similar program could be supported through port sampling (rather than onboard sampling) given the lack of sex or size limits in the fishery. However, if high-grading occurs, onboard observers would be necessary for the program to work.

3.3.6 Recommendations

In the long-term, we recommend requiring logbooks in the commercial spot prawn trap fishery and using data from these logbooks to develop an empirical harvest control rule for spot prawn. The logbooks would provide the added benefit of helping to guide efficient and effective management of marine life entanglement risk should this risk escalate as it has in the Dungeness crab fishery. While data are being collected from logbooks to support a robust harvest control rule, we suggest adopting one of the other approaches as an intermediate action. The collection of spawner data through port sampling would be preferred but more expensive. These data could eventually support the development of a length- or age-structured stock assessment when paired with the logbook CPUE index. However, the yield-per-unit-area approach could be set up more quickly and cheaply and may therefore be preferable.

3.4 Red sea urchin

3.4.1 Current management

Red sea urchin (*Mesocentrotus franciscanus*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting red sea urchin.

Action	**Commercial divers**	**Recreational**
Catch	No limits	Daily bag limit (35 / day)
Effort	Limited entry (300 permits) - program to reduce to 150	*Open access*
Gear	Rakes, airlifts, hand held gear	*No rules*
Time	Regional day of week restrictions	*No limits*
Sex	*No limits*	*No limits*
Size	Regional slot quotas	*No limits*
Area	*No limits*	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"Currently, there is no direct reference point for determining whether the stock is overfished nor are there procedures in place specific to the red sea urchin fishery to halt overfishing when it is found to be occurring. Landings are monitored using commercial landing receipts and are used as indicators for the fishery both in the north and south separately and together statewide. Landing receipts can act as an indicator for CPUE showing changes in pounds per landing (Figure 3-1). Using landing receipts for CPUE is not ideal because it does not indicate hourly effort as the commercial logbooks do. In addition, multiple day trips are not recorded on the landing receipts. The current commercial logbooks require individual divers to record hours underwater per day or change in location of diving; previous versions of the logbook allowed multiple divers to report their information in aggregate. These differences in reporting requirements make it difficult to establish a clear relationship between logbooks and landing receipts at this time."*

We provide a summary of how managers could establish reference points using fishery-dependent or fishery-independent indices of relative abundance or using a length-structured stock assessment approach. We also discuss the management actions that could be taken in response to a reference point being exceeded based on insights from the management strategy evaluation for the species (Valencia et al., 2021).

3.4.2 Fishery-independent index of relative abundance

The performance of the red sea urchin fishery could potentially be tracked using a fishery-independent index of relative abundance generated from the National Park Service Kelp Forest Monitoring Program (KFMP) but more information on data availability is needed.

As reported in the ESR for warty sea cucumber, the KFMP has been monitoring the size and density of many fish, invertebrates, and algae at 17 marine protected area (MPA) sites and 19 fished sites around the northern Channel Islands since the early 1980s. However, the ESR for red sea urchin only visualizes data since 2013 for red sea urchins. More clarity is needed about how much data is actually available for red sea urchin from this monitoring program.

If more data are available, the development of an empirical harvest control rule pegged to the KFMP index of relative abundance is an attractive management option because the fishery is largely concentrated in the vicinity of the northern Channel Islands where these data are collected (**Figure 1**). This makes these data a useful indicator of the status of the resource.

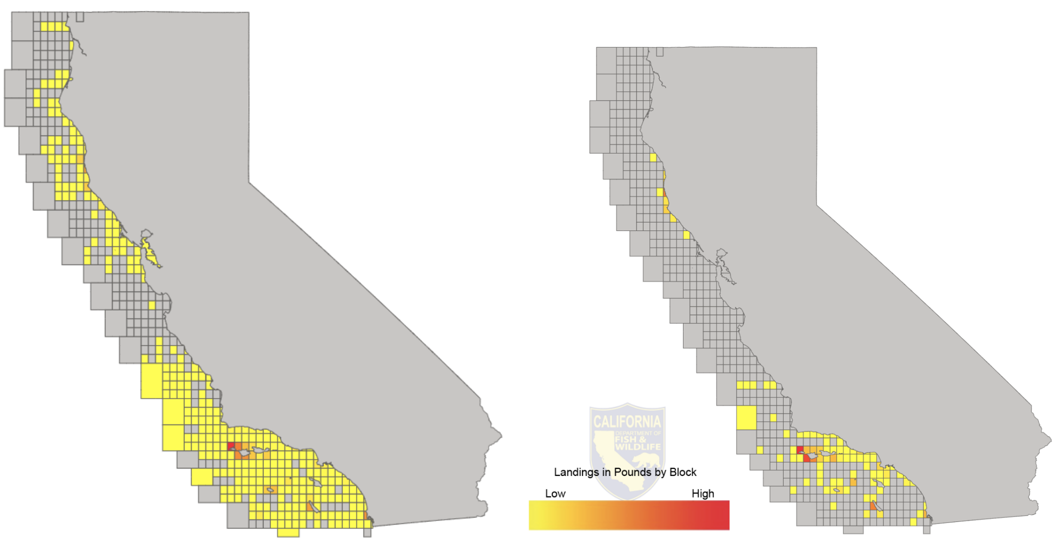


Figure 1. The location of fishing effort (left) since 1980 and (right) since 2013 for red sea urchin.

3.4.3 Fishery-dependent catch-per-unit-effort

The availability of the KFMP relative abundance index, whether it extends back to 2013 or 1982, provides the opportunity to evaluate the utility of catch-per-unit-effort indices generated from fishery-dependent data to guide management of red sea urchin. The ESR and the Hordyk et al. (2017) report multiple issues with the fishery-dependent data that require rigorous examination:

1. The ESR suggests that logbooks provide accurate information on hours but inaccurate information on location;

2. The Hordyk et al. (2017) report suggests that logbook harvests do not sum to match fish ticket harvests, suggesting that the logbooks underreport catch; and
3. The Hordyk et al. (2017) report suggests that commercial catch-per-unit-effort may track roe quality better than resource abundance given that urchin are harvested for their roe.

A reliable catch-per-unit-effort index could potentially be calculated by leveraging the strengths of each dataset such that effort estimates come from logbooks and landings estimates come from fish tickets. However, the resulting index should be validated against the KFMP abundance to evaluate the hypothesis that fishery-dependent catch-per-unit-effort tracks the quality of red sea urchin roe more than it tracks the abundance of red sea urchin. This exercise is critical before assessing the viability of a catch-per-unit-effort index.

Furthermore, CDFW would need to support the key punching of many unentered logbooks. As of March 22, 2024, a few thousand sea urchin dive logs need to be entered from 2010-2023 (Georgia Martel, personal communication). Furthemore, as suggested by Hordyk et al. (2017), we confirmed that logbook landings are consistently less than fish ticket landings (**Figure 2**), even in the 1990s, suggesting more logbooks may be missing.

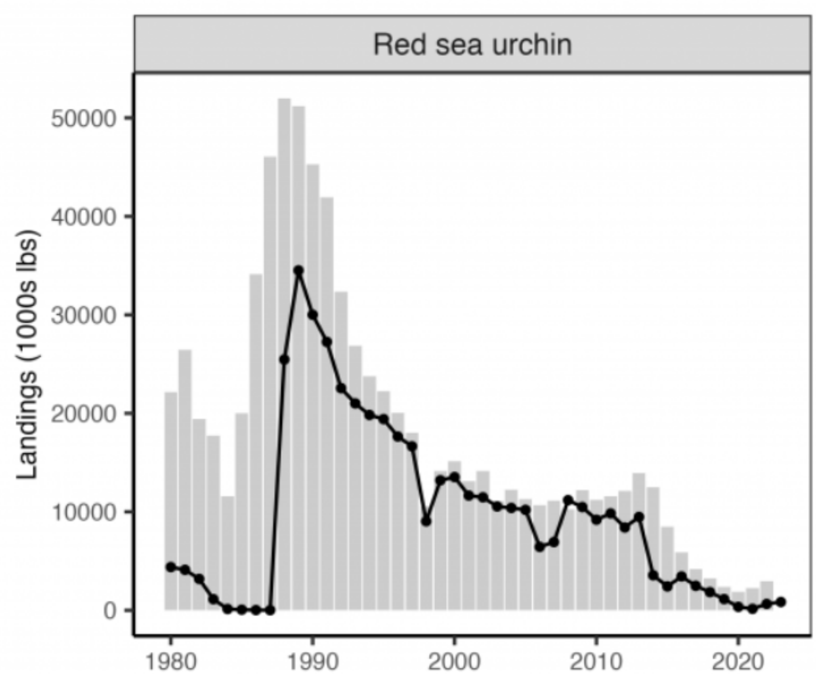


Figure 2. A comparison of annual red sea urchin landings from the California dive fishery in logbooks (lines) versus the fish tickets (bars).

3.4.4 Length-structured stock assessment

The 2003 stock assessment of green sea urchin (*Strongylocentrotus drobachiensis*) in Maine (Chen & Hunter, 2003) provides an instructive example of the type of assessment that could be conducted for red sea urchin in California, especially if the KFMP abundance data extend back to 1982. This length-structured stock assessment is fit to a fishery-dependent CPUE index (pounds per diver hour) and the length composition of the catch. However, the application of this approach would require the explicit collection of data on the size composition of the catch. This is listed as a high need in the *“Future Management Needs”* section of the ESR.

While waiting on the collection of this data and the dedication of resources to support a stock assessment, red sea urchin could be assessed using either an empirical reference point based on the KFMP index or based on a biomass dynamic model fit to the KFMP index. Both approaches are used in the management of green sea urchin in Canada (DFO, 2021).

3.4.5 Management strategies

The management strategy evaluation (MSE) of management procedures for red sea urchin provides useful insights into the management options that could be considered if the fishery were to exceed an established reference point (Valencia et al., 2021).

The MSE evaluated management procedures considered feasible given governance constraints and data availability under a range of climate change scenarios. The climate scenarios were designed to reflect a range of hypotheses including reduced reproductive capacity, increased mortality due to starvation or disease events, and reduced or variable growth. They also looked at scenarios in which these conditions re-occur periodically in response to oceanic variation.

The MSE found that no single management strategy was robust to all of the uncertainty scenarios modeled. However, effort limits, catch limits, and the current size limit were robust to the majority of the scenarios. The management procedures that set catch limits in response to changes in an index of abundance were advantageous because they allow managers to respond to declines in stock abundance when they occur by reducing catches, while also increasing catch limits during times when urchin are abundant. Such an empirical harvest control rule could be pegged to the KFMP abundance index and could be parameterized through a retrospective analysis of oceanographic conditions, the KFMP abundance index, and fisheries harvests.

3.4.6 Recommendations

We recommend supporting a port sampling program to gather information on the size composition of the catch to ultimately support a length-structured stock assessment similar to that of Chen and Hunter (2003). In the meantime, we recommend using the KFMP data to develop either an empirical harvest control rule or to estimate status relative to reference points using a biomass dynamic model (a much simpler alternative to a length- or age-structured stock assessment). Managing the red sea urchin fishery in response to specified reference points would be valuable given the large and consistent decline in red sea urchin landings since 1990.

3.5 Pacific angel shark

3.5.1 Current management

Pacific angel shark (*Squatina californica*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting Pacific angel shark.

Action	Commercial set gillnet	Recreational
Catch	*No limits*	Default daily bag limit (10 / day)
Effort	Limited entry	*Open access*
Gear	Gear specifications	*No rules*
Time	*No limits*	*No limits*
Sex	*No limits*	*No limits*
Size	Female: >42” total length Males: >40” total length	*No limits*
Area	Set gillnets outside 3nm from mainland and 1nm from islands	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *“Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild”* of the Enhanced Status Report (ESR) reads:

> *“There are no formal overfishing threshold criteria for Pacific angel shark. However, landings are tracked in both the commercial and recreational sectors, and given the low landings that have occurred since the ban on gill net and trammel nets in the early 1990s, there are currently no concerns about overfishing occurring on this stock. Based on the limited data available it appears current management is effective; however, it is unclear whether Pacific angel shark populations have rebounded. If landings increase significantly or if it appears anglers begin targeting Pacific angel shark again, this may indicate the fishery needs management changes to ensure sustainability.”*

The most significant improvements that can be made to understanding the status of Pacific angel shark is to understand the magnitude of discards in the set gillnet fishery and the level of mortality associated with these discards. Although landings are low, they may not fully represent the impacts of fishing if discards and discard mortality are high. We discuss the steps required to estimate discards and discard mortality for the fishery in the section below.

3.5.2 Estimate discards and discard mortality

Estimating discards and discard mortality of Pacific angel shark in the commercial set gillnet fishery depends on the use of observer data from the fishery. There was observer coverage in the California set gillnet fishery from 1983-1995, 1999-2000 (Monterey Bay only), 2010-2013, and in 2017 (**Figure 1**). The observer program was run by CDFW from 1983-1989 and by the National Oceanic and Atmospheric Administration from 1990 onwards. Observers collected information on the amount and fate of catch, the length composition of the catch, the location and time of the catch, and characteristics of the gear used to target the catch.

Unfortunately, analysis of the observer data by Fang et al. (in prep)[1] revealed that a large portion of the data collected from the northern strata in the 1980s have been lost (**Figure 1**). Fang et al. (in prep) recovered a portion of this data in Monterey Bay, but the rescued records only describe bycatch of mammals and seabirds. The Pacific angel shark data remain lost.

The recovery of these lost data would greatly improve estimates of discards and discard mortality of Pacific angel shark in the set gillnet fishery.

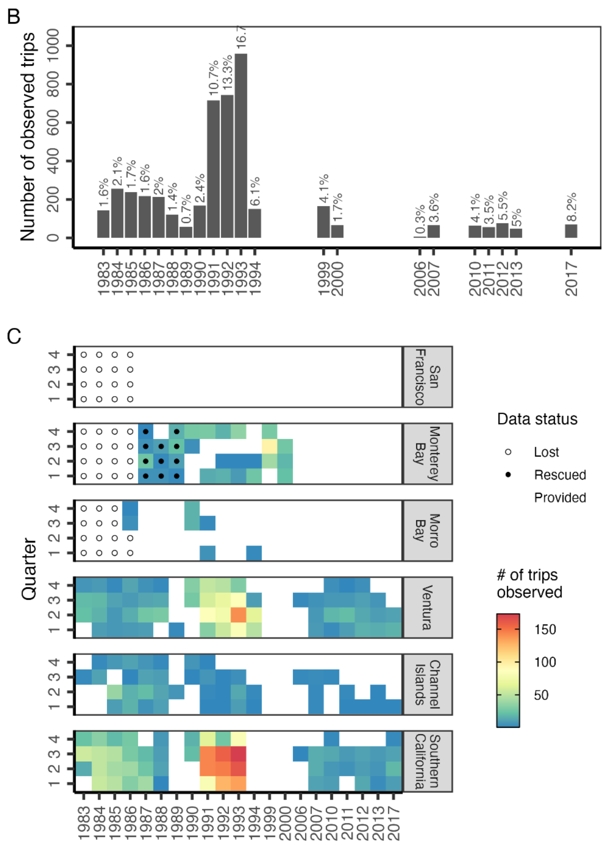


Figure 1. Observer coverage in the California set gillnet fishery. Panel **B** shows the number of observed trips (vessel-days) over time. The dark labels show the estimated percent of trips that were observed. Panel **C** shows the number of observed trips across the space and time. Quarters are defined as: 1 = JFM, 2 = AMJ, 3 = JAS, and 4 = OND (Fang et al. in prep).

An initial analysis of these data (CDFW, 2023) suggests that Pacific angel sharks are caught in 30% of set gillnet fishing trips and that 12% of discarded sharks die. However, this report only

[1] The author of this report, Dr. Christopher Free, is the supervising author on this paper.

evaluated the observer data ranging from 2007 to present. Thus, it excludes the vast majority of observer records. A reanalysis of all the data, including the lost data, would be instructive.

Furthermore, total discards for the set gillnet fleeting could be reconstructed from fish tickets and observer data using the same methods that the Groundfish Expanded Mortality Multiyear (GEMM) program used to estimate discards from the the open-access California halibut trawl fishery (Somers et al., 2021). The approach essentially assumes that the ratio of discards to target species catch is the same across all fishing trips. Thus, discards can be calculated as:

$$D = \frac{\sum_{t} d_t}{\sum_{t} r_t} \times F$$

Where *D* is the discard estimate for Pacific angel shark, *t* is the number of observed gillnet sets, *d* is the observed discard weight of Pacific angel shark, *r* is the observed retained weight of California halibut, and *F* is the weight of retained California halibut recorded on fish tickets for the fleet (expansion factor). The discard ratio could be calculated for each year with sufficient observer data and then could be used for the closest year without observer data. The ratios could also be calculated for meaningful spatial, temporal, or gear-based strata if necessary.

The reconstruction of Pacific angel shark discards would also be helpful to the management of angel sharks because it would help determine whether a reliable index of abundance could be derived from gillnet logs. If Pacific angel sharks commonly occur in logged gillnet sets and most of the caught Pacific angel sharks are landed, then it may be possible to calculate a reliable fishery-dependent catch-per-unit-effort index. This index could be used to track the status of Pacific angel shark and to trigger management interventions when necessary.

3.5.3 Recommendations

Our recommendations for improving ability to track the status of Pacific angel shark are to: (1) recover the lost observer data; (2) estimate discards and discard mortality using the observer data; and (3) if possible, calculate a fishery-dependent catch-per-unit-effort index from the gillnet logbooks. These efforts are valuable given Pacific angel shark's "Near Threatened" IUCN classification and the interest of conservation organizations in this species (Oceana, n.d.).

3.6 Barred sand bass

3.6.1 Current management

Barred sand bass (*Paralabrax nebulifer*) are managed using a number regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting barred sand bass.

Action	**Recreational**
Catch	Default daily bag limit (10 / day)
Effort	*Open access*
Gear	*No rules*
Time	*No limits*
Sex	*No limits*
Size	*No limits*
Area	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"The Department has not established overfishing criteria for the barred sand bass fishery. There is no specific trigger for making a regulation change in this fishery and any decision to re-evaluate the current management strategy is based on supporting evidence from multiple sources. Prior to the regulation change in 2013 staff noted a concurrent and sustained drop in catch rates and relative fish abundance, paired with a potential recruitment failure, as described in Jarvis et al. (2014a).*
>
> *Department staff continue to monitor catch, effort, and size trends annually, utilizing both fishery-dependent and fishery-independent datasets. These data are evaluated relative to historic trends and environmental factors (Jarvis et al. 2014a). A stock assessment and FMP have not been completed for the barred sand bass resource. Sustainability of the fishery is evaluated through various methods including the Data Limited Methods Toolkit to conduct a Management Strategy Evaluation (MSE) of alternative rebuilding methods and length at age-based models. An MSE for barred sand bass was completed in 2020 (Appendix A) but requires further refinement. Staff are also monitoring the effectiveness of the size and bag limit implemented in 2013 by sampling the number and size of barred sand bass discarded in the CPFV fishery. Since more reproductively mature barred sand bass are now left in the population (i.e. 12-14 in fish) we expect that more offspring are being produced. Thus, as these offspring reach a size that is susceptible to harvest, at 5 or 6 yr of age, we expect to see a more even distribution of*

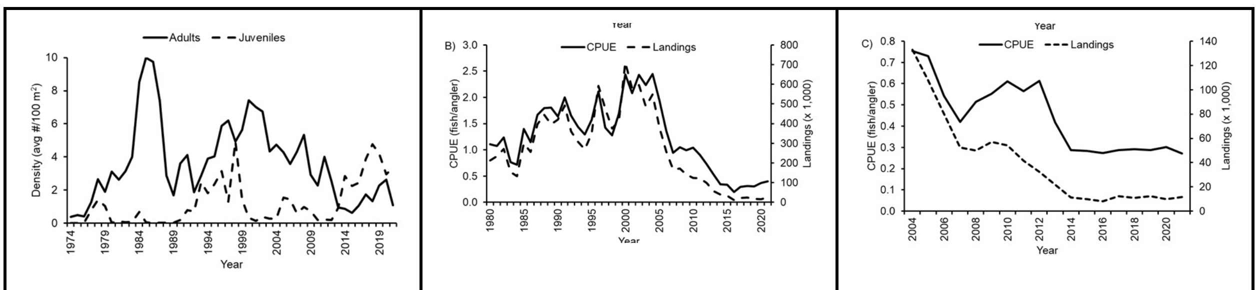
younger age classes of sublegal fish in the discards as the new recruits enter the fishery. As these fish reach legal size at about 8 yr, an increase in the ratio of kept to discarded fish should also occur. Therefore, if the number of kept fish does not increase and we do not observe large cohorts of sublegal fish entering the fishery as discards in the 5 to 10 yr following the regulation change, further regulation change may be needed."

Barred sand bass are very data-rich and are good candidates for the development of a stock assessment to track population health and to guide management. We discuss how a length-structured stock assessment for barred sand bass could be developed below.

3.6.2 Length-structured stock assessment

This data-rich fishery is a good candidate for a length-structured stock assessment because it has multiple indices of relative abundance as well as length composition of the catch available.

First, there is an index of annual juvenile (≤25 cm total length prior to 1991 and ≤15 cm total length thereafter) and adult (≥25 cm total length) barred sand bass abundance at King Harbor, Redondo Beach, Los Angeles County from 1974 to 2021 collected by the Vantuna Research Group at Occidental College (**Figure 1A**). This fishery-independent index of relative abundance is the gold standard for stock assessment and is sourced from the center of the fishing grounds for barred sand bass (**Figure 2**). Second, a standardized fishery-dependent catch per unit effort index is tracked for both the party boat (**Figure 1B**) and private boat (**Figure 1C**) fleets. The index for the party boat fleet is derived from CPFV logbooks and the index for the private boat fleet is derived from the California Recreational Fisheries Survey (CRFS) port sampling program. Third, there is size composition of the catch for both fleets from the CRFS (CRFS) port sampling program. Together, these data make the fishery quite data-rich and a good candidate for a length-structured stock assessment.



A. Fishery-independent	B. Party-boat CPUE	C. Private-boat CPUE

Figure 1. Indices of relative abundance for barred sand bass based on (A) fishery-independent scientific sampling by the Vantuna Research Group, **(B)** fishery-dependent catch-per-unit-effort (CPUE) for the party boat fleet based on CPFV logbooks, and **(C)** fishery-dependent catch-per-unit-effort (CPUE) for the private boat fleet based on the California Recreational Fisheries Survey (CRFS) port sampling program.

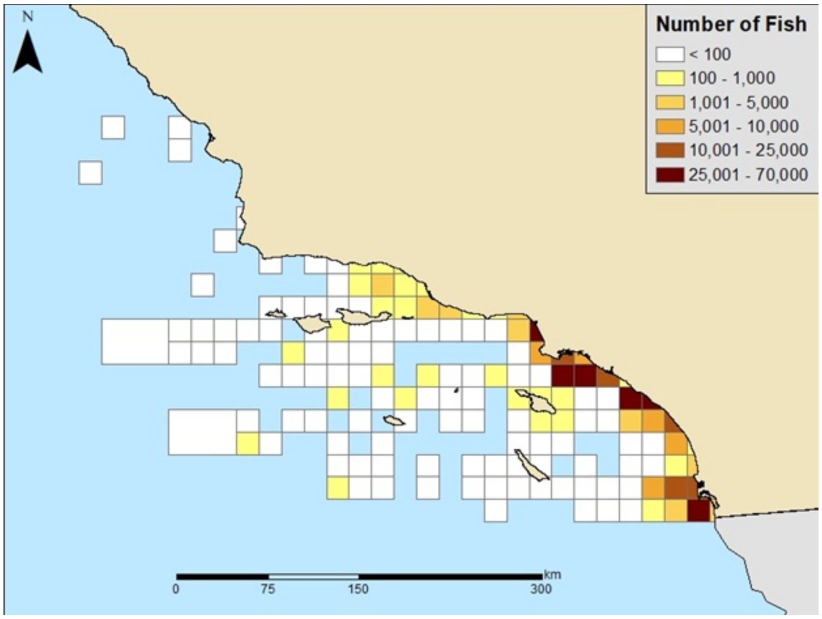


Figure 2. Location of CPFV fishing effort for barred sand bass based on CPFV logbooks.

When developing a stock assessment, we recommend downweighting the fishery-dependent catch-per-unit-effort indices relative to the index of relative abundance from the scientific survey. We recommend this not only because data from scientific surveys are more rigorously recorded and involve standardized sampling designs but also because barred sand bass are known to form spawning aggregations, which the fishery is known to target. This can cause hyperstability in fishery-dependent catch-per-unit-effort indices, where catch rates remain high despite declines in population abundance. The scientific survey is less vulnerable to this concern and should therefore be upweighted in the stock assessment.

We also recommend time-blocking survey catchability to account for the impact of management regulations that shifted significantly in 2013. In 2013, both stricter size and bag limits were introduced to address concerns regarding the status of barred sand bass and kelp bass populations. Time-blocking survey catchability should account for any resulting shift in targeting.

Finally, we advise using the raw length composition data in a stocks assessment rather than using the length-converted age compositions shown in the ESR (**Figure 2**). This would allow for the model to be fit to data with fewer assumptions regarding the length-age relationship.

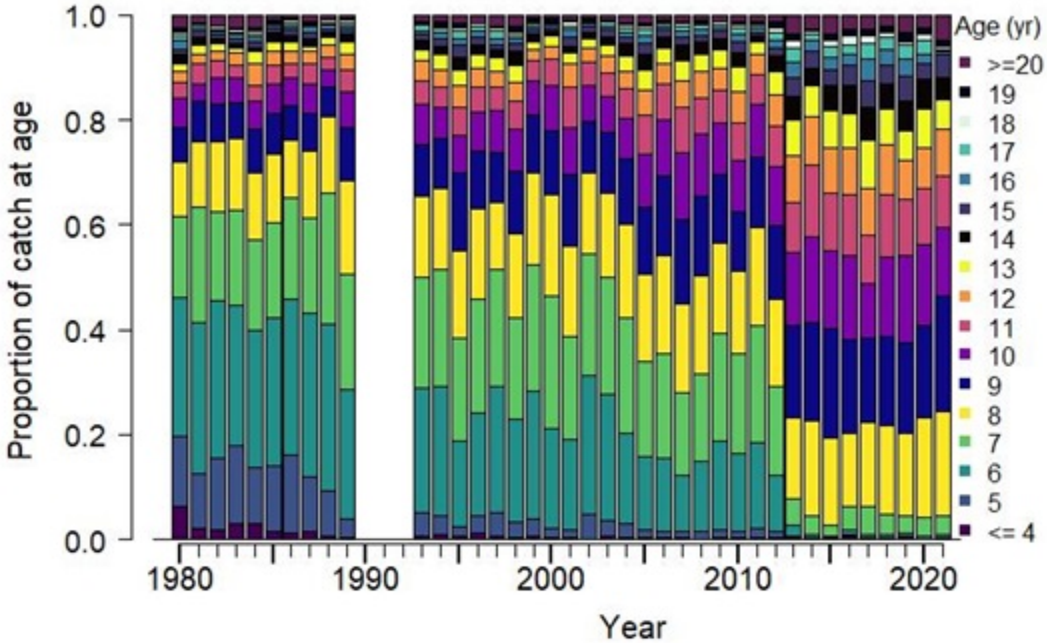


Figure 3. Age structure of harvested barred sand bass from 1980 to 2021. Age classes were converted from length data of retained catch from all fishing modes. A size limit increase in 2013 altered the distribution of retained fish. No data collected from 1990 to 1992.

3.6.3 Management strategies

The management strategy evaluation (MSE) of management procedures for barred sand bass provides useful insights into the management options that could be considered if the fishery were to exceed an established reference point (Valencia et al., 2021).

The MSE suggested that the current size limit and bag limit are unlikely to achieve conservation objectives and to facilitate population recovery.

As a result, the authors evaluated a number of alternative management procedures including size limits, slot limits, effort limits, and bag limits to determine which are most likely to improve stock conditions. Although many of these procedures could achieve conservation objectives, they would be difficult to implement for various reasons. While slot limits with only 0.5 to 1-inch slots were robust to uncertainty, the very small size range would make them difficult to enforce. Additionally, there was concern that large size limits (which were generally higher performing management options) would create intense fishing pressure on the largest and oldest fish in the stock, which was not viewed favorably despite modeling support. As a result, bag limits were identified as most promising.

Bag limit reductions were robust to a number of key uncertainties and were able to promote stock recovery over medium-term time periods (10-20 years), which is a priority for this fishery. However, bag limits were sensitive to assumptions about effort, both the amount of fishing effort currently applied to barred sand bass as well as how bag limit changes impact future fishing effort. This is a key uncertainty, and additional information about current fishing effort as well as bag limit impacts would improve model outputs. Bag limit performance was also sensitive to assumptions about the discard mortality rate of the fishery, which may be higher than reported.

Bag limits were difficult to model within the MSE because they require information about how a change in bag limit impacts both the catch and fishing effort, which is likely to vary depending on both the limit and the stock size. The authors approximated the impacts of bag limits using bag distribution data from California Recreational Fisheries Survey (CRFS) sampling program. However, the authors recommended additional research to develop quantitative predictions of how changes in bag limits alter fishing effort, as well as further development of the MSE framework to better model this important management tool for recreational fisheries. Much of this work is already underway in collaboration between CDFW, openMSE, and bluematter (Carruthers et al., 2024).

CDFW is concerned about barred sea bass and is considering steps to protect spawning aggregations (Huff McGonigal, personal communication). The implementation of such policies would have the knock-on benefit of improving the reliability of a fisheries-dependent CPUE index by reducing the hyperstability in catch rates introduced by targeting spawning aggregations. If implemented, managers should anticipate a downward adjustment in the scale of fishery-dependent CPUE and an increase in the variability of the index.

3.6.4 Recommendations

We recommend developing a length-structured stock assessment for this data-rich species. When building the length-structured stock assessment we recommend: (1) upweighting the fishery-independent index of relative abundance to reduce the impact of hyperstability in the fishery-dependent CPUE index; (2) time-blocking estimates of survey catchability to account for the impact of management regulations that shifted significantly in 2013 (i.e., stricter size and bag limits) and that could impact survey catchability; and (3) using the raw length composition data in a length-structured stock assessment rather than using length-converted age compositions in an age-structured stock assessment to better represent uncertainty.

3.7 Kellet's whelk

3.7.1 Current management

Kellet's whelk (*Kelletia kelletii*) is managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting Kellet's whelk.

Action	Commercial	Recreational
Catch	100,000 lb annual catch limit	Daily bag limit (35 / day)
Effort	Lobster/rock crab: Limited entry	*Open access*
Gear	Directed: Hand Incidental: Lobster/rock crab	Hand: Skin diving, SCUBA south of Yankee pont Hook and line
Time	July 1 - 1st Wednesday after Mar 15	July 1 - 1st Wednesday after Mar 15
Sex	*No limits*	*No limits*
Size	*No limits*	*No limits*
Area	No take within 1000 ft of low tide mark	No take within 1000 ft of low tide mark

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"No objective overfished or overfishing benchmark has been designated due to the incidental nature of the Kellet's whelk fishery and the relative stability of the landings. However, landings, effort and value are monitored. Multiple years of the TAC being reached, a sudden drop in landings, or rise in effort or price may lead to an investigation by Department staff, and if warranted, the development of adaptive management recommendations."*

This text suggests that CDFW monitors multiple data streams to determine whether management interventions are necessary. However, the text lacks necessary specifics about how indicators are calculated, evaluated, and responded to when exceeded. We provide recommendations for how reference points for Kellet's whelk could be defined and tracked.

3.7.2 Length-based indicators

Whelk in Wales (United Kingdom) are monitored and managed using a series of length-based indicators (Hold et al., 2022). These indicators depend on the collection of data to document the size composition of the catch. With these data, the following indicators can be calculated:

1. **$L_{max5\%}$:** Mean size of the largest 5% of the catch;

2. **P_{mega}:** Proportion of "megaspawners", where a megaspawner is 1.1 times larger than the length at which the biomass of a cohort is maximized (L_{opt});
3. **$L_{25\%}$:** Shell length at the 25% percentile of the landings;
4. **L_c:** Length at first capture

More details on the theory and equations behind these indicators can be found in (Froese, 2004) and (Cope & Punt, 2009). Notably, L_{opt} can be derived from growth parameters as:

$$L_{opt} = L_{inf} \times [3 / (3 + M/K)]$$

where L_{inf} is the asymptotic length, M is natural mortality, and K is the growth rate. The references are assessed against the reference points defined in **Table 1**.

Indicator	Green	Amber	Red
1: $L_{max5\%}$	$L_{max5\%} / L_{inf} > 0.8$	$L_{max5\%} / L_{inf} = 0.8$	$L_{max5\%} / L_{inf} < 0.8$
2: P_{mega}	$P_{mega} > 0.3$	$P_{mega} = 0.3$	$P_{mega} < 0.3$
3: $L_{25\%}$	$L_{25\%} / L_{MAT} > 1$	$L_{25\%} / L_{MAT} = 1$	$L_{25\%} / L_{MAT} < 1$
4: L_c	of $L_c / L_{MAT} > 1$	of $L_c / L_{MAT} = 1$	of $L_c / L_{MAT} < 1$

Table 1. Length-based reference points used to manage Welsh whelk stocks (Hold et al., 2022). Stocks in the green, amber, and red zones are thought to be in good, satisfactory, and poor status, respectively.

In addition to the collection of size composition data, the calculation of these indicators and reference points depends on population-specific estimates of several life history parameters including: length at maturity (L_{mat}), Von Bertalanffy growth parameters (K, L_{inf}, t_0), and natural mortality (M). Because natural mortality is especially difficult to measure, sensitivity analyses should be conducted around alternative levels of assumed natural mortality. This is well aligned with the *"Future Management Needs and Directions"* section, which identifies "*Fill data gaps and improve biological and life history information"* as a high priority need.

3.7.3 Catch-per-unit-effort or index of relative abundance indicators

In Canada, whelk are managed using non-standardized fishery-dependent catch-per-unit-effort (CPUE) as an indicator of stock health and reference points pegged to this indicator (DFO, 2022). Reference points are calculated assuming that the maximum mean annual CPUE is a proxy for B_0 and that 30% of this value is a proxy for the limit reference limit. This reference point was selected based on best practices (Sainsbury, 2008). **Figure 1** illustrates the application of this approach to whelk in Canada.

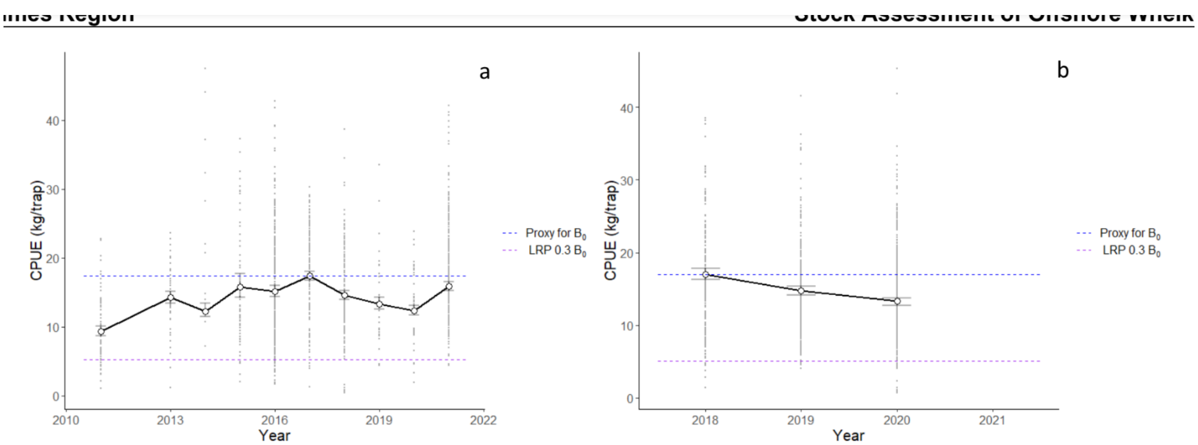


Figure 1. Mean catch-per-unit-effort (CPUE) in the whelk fishery compared to the limit reference point, which is 0.3 of the B_0 proxy (DFO, 2022).

A fishery-dependent catch-per-unit-effort indicator could be calculated using the commercial dive logbooks, which the ESR for warty sea cucumber asserts is a reliable source of effort information. However, the ESR for warty sea cucumber and Hordyk et al. (2021) both state that the logbook harvests are much smaller than the fish ticket harvests, suggesting underreporting for this species. This should be investigated for whelk as well.

Fortunately, there are several indices of relative abundance available from scientific surveys that could render this approach unnecessary or could at least be used to validate or refute the fishery-dependent CPUE. These indices can be used in the same framework and have the benefit of coming from rigorous scientific surveys. There are surveys for each of the major whelk fishing grounds, as shown in **Figure 2**.

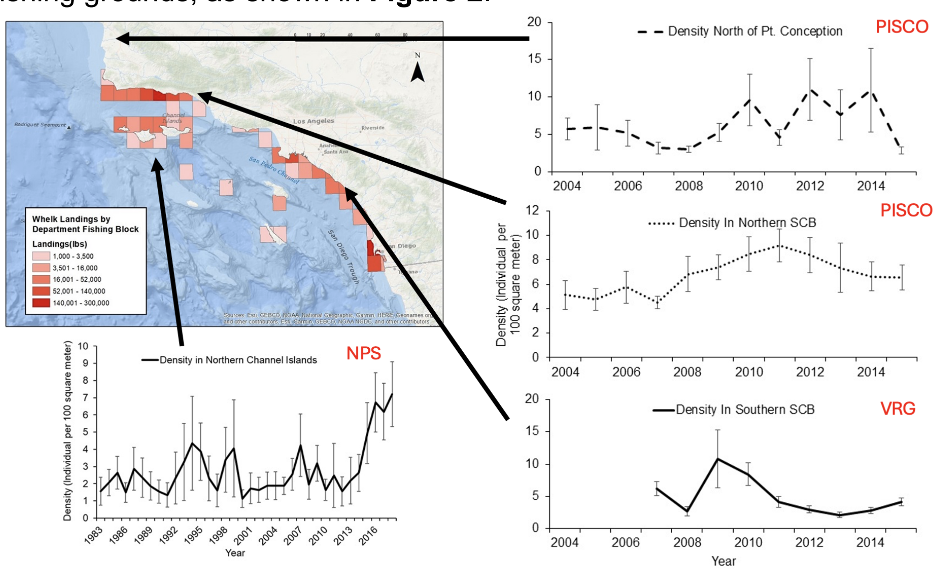


Figure 2. Whelk fishing grounds in California and time series of relative whelk abundance from three different scientific surveys: PISCO, NPS KFMP, and Vantuna Research Group (VRG).

3.7.4 Management strategies

If a reference point is exceeded, managers could consider implementing a size limit that only allows the harvest of individuals larger than the estimated 60 mm length at maturity. This is aligned with the management approach currently used in Wales, where only individuals larger than 65 mm can be harvested (the species- and population-specific length at maturity).

3.7.5 Recommendations

We favor developing an empirical harvest control rule for each whelk fishing ground using the relevant scientific survey index over tracking status using length-based indicators for several reasons. First, this leverages existing programs and does not require new investments to start port sampling programs to sample the length composition of a relatively small commercial fishery. Second, the performance of length-based indicators is highly sensitive to knowledge of life history parameters whereas abundance indices are more immediate reflections of population trends. Finally, leveraging regional surveys can account for differences in regional productivity.

3.8 Yellowtail

3.8.1 Current management

Yellowtail (*Seriola dorsalis*) is managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting yellowtail.

Action	Commercial	Recreational
Catch	Seasonal trip limits (May 1-Aug 31)	Daily bag limit (10 / day; 5 must be >24” FL)
Effort	Gillnet is limited entry	*Open access*
Gear	Gillnet: >3.5” mesh size Purse seine / round halt net not allowed	*No limits*
Time	Year-round, but seasonal trip limits	*No limits*
Sex	*No limits*	*No limits*
Size	>28”	Daily bag limit (10 / day; 5 must be >24” FL)
Area	Hook and line: no limits Gillnet: >3nm from mainland, >1nm from islands	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *“Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild”* of the Enhanced Status Report (ESR) reads:

> *“There are no formal overfishing threshold criteria or measures put in place to rebuild the stocks for yellowtail. Based on the limited data available it appears current management is effective and there are currently no concerns about overfishing occurring on this stock.”*

There is strong belief that the yellowtail population is healthy given its life history (it reaches maturity in 3-4 years and has high fecundity) and that it has supported significant sport and commercial fisheries since the early 1900s. However, the tracking of a fishery-dependent catch-per-unit-effort index would help to support this belief. Furthermore, given the length of high exploitation in the fishery, the ESR would benefit from more transparency about pre-1980s fisheries exploitation to avoid shifting baseline challenges (Schijns & Pauly, 2022).

3.8.2 Incorporate historical data to avoid shifting baseline syndrome

The ESR only reports commercial catch, recreational catch, and recreational catch-per-unit-effort since 1980, yet yellowtail were heavily exploited long before this period. Collins (1973) presents data as far back as 1916 and indicates that the stock was much more heavily exploited in the first half of the 20th century (Collins, 1973). Landings were nearly 12x higher than the data shown in the ESR. It is not inconceivable that the fishery could be depleted as a result of this high exploitation and that sustained catches since 1970 do not necessarily provide evidence of sustainability when taking historical context into consideration. The ESR and all future analysis should be sure to consider these historical data. This advice applies to all ESR species.

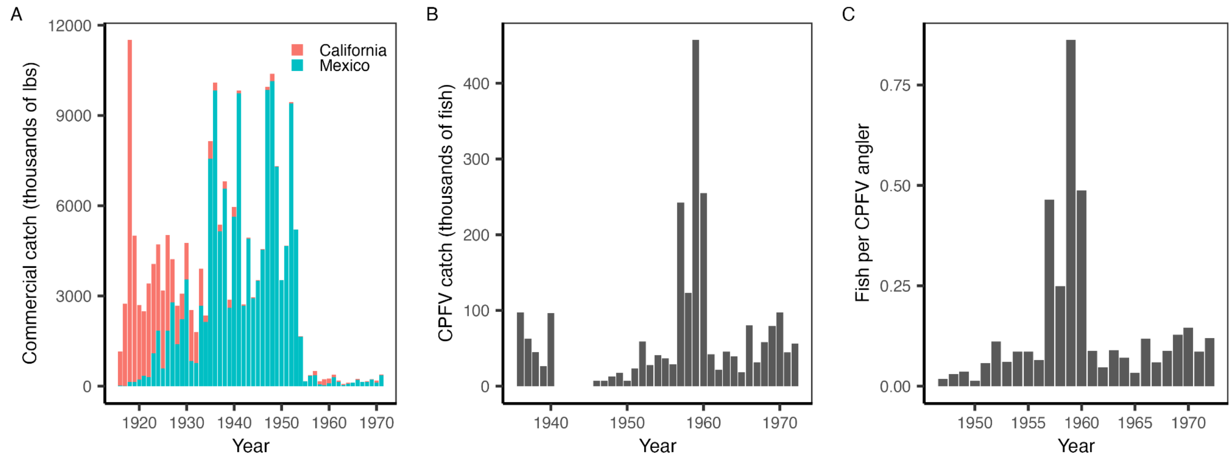
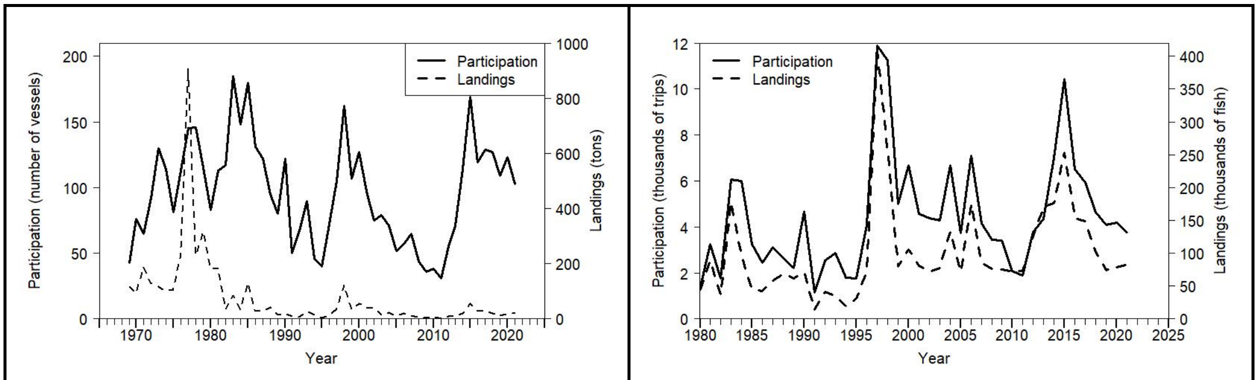


Figure 1. Time series of **(A)** commercial catch; **(B)** CPFV catch; and **(C)** CPFV catch-per-unit effort from Collins (1973).



A. Commercial catch	**B.** Recreational catch

Figure 2. Time series of **(A)** commercial catch and **(B)** CPFV catch from the ESR. *Note that in Panel A the units are incorrectly reported as being in tons. The caption for the figure in the ESR says that the units are actually in 1000s of pounds: a ton is equal to 2000 pounds.*

3.8.3 Fishery-dependent catch-per-unit-effort

The health of the yellowtail stock could be tracked by developing a standardized fishery-dependent catch-per-unit-effort index as was done for the 2011 California halibut stock assessment (Maunder, 2011; Maunder et al., 2011). This index was developed using the CPFV logbooks using self-reported catch and effort information to calculate an index in terms of fish per angler hour (**Figure 3**). Given that the ESR reports that yellowtail landings, and presumably abundance, fluctuate with water temperature – where warmer years coincide with higher landings and cooler years coincide with lower landings – management triggers for yellowtail could be based on dual reference points of catch-per-unit-effort and water temperature (**Figure 3**). This is similar to the system in place for California pink shrimp (see *Section 2.1*) and Oregon Dungeness crab (see *Section 3.1*).

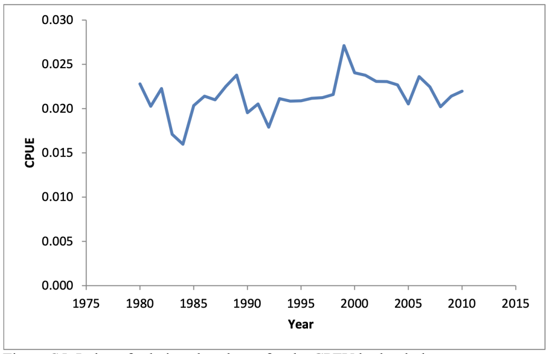
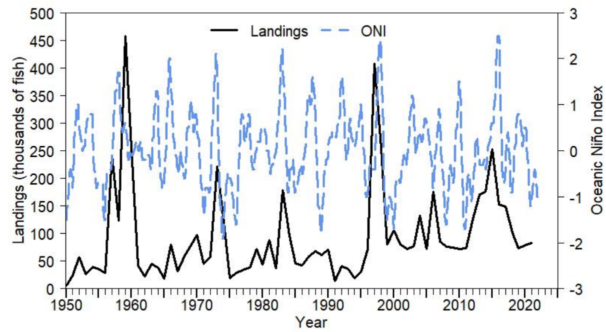


Figure S5. Index of relative abundance for the CPFV logbook data.



A. Example CPUE index	B. Example environmental index

Figure 3. (A) An index of relative abundance for California halibut based on a standardized fishery-dependent catch-per-unit-effort index calculated from the CPFV logbooks. **(B)** An example environmental index for yellowtail as reported in the ESR for yellowtail.

3.8.4 Recommendations

We recommend transparency in the scale of historical landings for this species and all ESR species to avoid shifting baseline syndrome in the assessment of stock status (Schijns & Pauly, 2022). We also recommend developing an fishery-independent CPUE index using CPFV logbook data, as has been done for the California halibut stock assessment, to monitor yellowtail abundance. We recommend exploring the relationship between this index, fisheries catch, and ocean temperature to determine whether an empirical harvest control rule should consider (1) just the CPUE index or (2) the CPUE index and ocean temperature. California pink shrimp and Oregon Dungeness crab provide instructive examples of control rules with a dual CPUE and environmental covariate trigger.

3.9 Night smelt

3.9.1 Current management

Night smelt (*Spirinchus starksi*) are managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting night smelt.

Action	**Commercial**	**Recreational**
Catch	*No limits*	Daily bag limit (25 lb / day)
Effort	Gillnet is limited entry	*Open access*
Gear	Gillnet: >3.5" mesh size Purse seine / round halt net not allowed	*No limits*
Time	Year-round, but seasonal trip limits	*No limits*
Sex	*No limits*	*No limits*
Size	>28"	Daily bag limit (10 / day; 5 must be >24" FL)
Area	Hook and line: no limits Gillnet: >3nm from mainland, >1nm from islands	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *"Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild"* of the Enhanced Status Report (ESR) reads:

> *"Currently, there are no criteria in place to identify when night smelt fisheries are "overfished" or in decline. Aside from commercial fish tickets, there are no other available datasets to evaluate the status of night smelt in California. Small, short-lived, pelagic fishes such as sardine and anchovy, are prone to fluctuations in abundance whether they are fished or not, and despite the implementation of precautionary management strategies (McClatchie et al. 2018). Night smelt are short-lived, mature at 2 years, and have the capability to rebound quickly when environmental conditions are favorable (Slama 1994). The Department will continue to monitor fisheries landings data; however, the potential of overfishing is minimized by the relatively low take, and constraints on beach access."*

The small-scale, data-poor, boom-and-bust nature of this fishery makes it an especially challenging fishery to establish reference points for using conventional approaches. We recommend that it could be a good candidate for the application of the cumulative sum (CUSUM) quality control method for monitoring fisheries, as discussed in detail below.

3.9.2 CUSUM approach

Cumulative sum (CUSUM) quality control methods present a promising approach for monitoring the catch of data-limited species and for determining when patterns in the catch might signal a need for closer management attention. CUSUM methods detect persistent changes in an observed process by measuring the cumulative sum of deviations of the process from its mean (Hawkins & Olwell, 2012). By defining thresholds of expected variability, CUSUM can be used to identify when a process is “out-of-control”. CUSUM methods can be used to monitor the catch time series of data-limited fisheries and determine when either increases or decreases in the catch should trigger management attention (Scandol, 2003).

The CUSUM approach is implemented in three steps. First, a standardized catch time series, $C_{sd,t}$, is calculated by centering the observed catch time series, $C_{obs,t}$, on zero and by scaling it to unit variance:

$$C_{sd,t} = \frac{C_{obs,t} - mean(C_{obs,t})}{sd(C_{obs,t})}$$

Second, cumulative deviations from the process mean are calculated as the upper and lower arms of the CUSUM time series where the upper CUSUM arm, ϕ_t^+, is calculated as:

$$\phi_t^+ = \begin{cases} 0, & t = 0 \\ \max(0, \phi_{t-1}^+ + C_{sd,t} - k), & t > 0 \end{cases}$$

and the lower CUSUM arm, ϕ_t^-, is calculated as:

$$\phi_t^- = \begin{cases} 0, & t = 0 \\ \min(0, \phi_{t-1}^- + C_{sd,t} + k), & t > 0 \end{cases}$$

and *k* is known as the allowance. Finally, the catch time series is identified as “out-of-control” in year t if either the lower or upper CUSUM arms fall outside the decision interval (±*h*):

$$\phi_t^+ > h \text{ or } \phi_t^+ < -h$$

This is useful in a fisheries context because it can signal the need for management when catch time series rise or fall outside specified limits, both of which can be red flags (Scandol, 2003).

Values for the allowance parameter, *k,* and decision interval, *h*, can be tuned to data-rich fish stocks documented in the RAM Legacy Database, as was done by Free and Wiedenmann (2019) when applying the method to 14 data-limited stocks in California (**Figure 1**). This study included night smelt, which was identified to be stable and not in need of management attention.

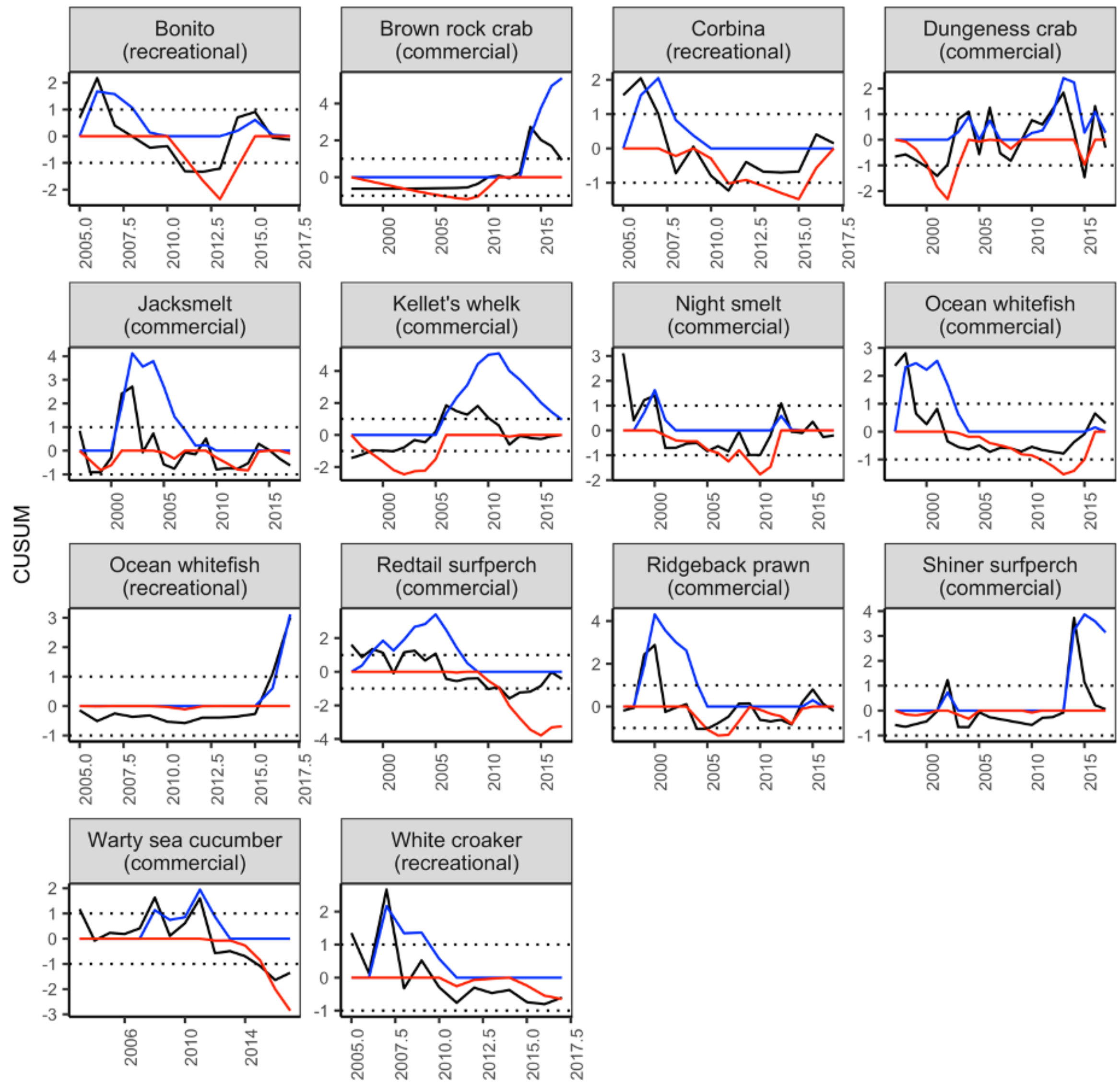


Figure 1. Application of the tuned CUSUM approach (h=1 and k=0.5) to the landings time series of the fourteen California fisheries (Free & Wiedenmann, 2019). Black lines indicated the standardized (i.e., centered and scaled) landings time series. Blue and red lines indicate the upper and lower CUSUM arms, respectively. Dotted lines indicate the decision intervals. If either the upper or lower CUSUM arms cross these thresholds in 2017, the fishery is classified as “out-of-control” or in need of attention.

3.9.3 Recommendations

The small-scale, data-poor, boom-and-bust nature of this fishery makes it an especially challenging fishery to establish reference points for using conventional approaches. We recommend that it could be a good candidate for the application of the cumulative sum (CUSUM) quality control method for monitoring fisheries and determining need for intervention.

3.10 Pacific bonito

3.10.1 Current management

Pacific bonito (*Sarda chiliensis*) is managed using a number of regulations (**Table 1**).

Table 1. Summary of management regulations in fisheries targeting Pacific bonito.

Action	**Commercial purse seine**	**Recreational**
Catch	*No limits*	Daily bag limit (10 / day; ≥5 must be >24” FL)
Effort	*No limits*	*Open access*
Gear	*No limits*	*No limits*
Time	Several regional seasons	*No limits*
Sex	*No limits*	*No limits*
Size	≥24” with several exceptions	Daily bag limit (10 / day; ≥5 must be >24” FL)
Area	Several seasonal restrictions	*No limits*

There are currently no codified procedures for evaluating the performance of these controls in achieving fisheries objectives or for adjusting these controls in response to performance indicators. *“Section 3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild”* of the Enhanced Status Report (ESR) reads:

> *“The Department has not established overfishing criteria for the bonito fishery. Due to bonito’s wide geographic range, highly migratory nature and shared stock with the Mexico purse seine fishery, their landings fluctuate greatly. Thus, the types of fishery-dependent data currently collected by the Department may not be indicative of their population status, which makes it challenging to actively manage. Based on their fast growth rate, high productivity, and available fishery-dependent data discussed in Sections 2 and 4, there are currently no concerns about the status of bonito and the existing regulations appear to provide enough protection to maintain the sustainability of the highly variable population off the California coast. However, if landings decrease in warm water periods, when bonito abundance typically increases, and if the recreational fishery continues to consist mostly of immature fish, this may indicate the fishery needs management changes to ensure sustainability.”*

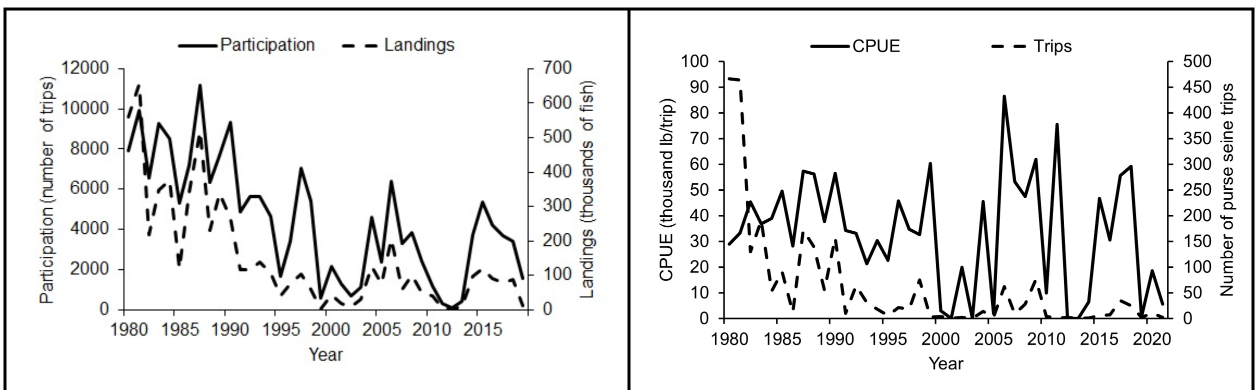
The ESR suggests that a limit reference point could be identified based on either a dual indicator – a decline in landings during a warm water period when bonito availability normally increases – or if the recreational catch remains dominated by immature fish. We provide recommendations for how such limit reference points could be derived below.

3.10.2 Dual temperature and landings indicators

The management of California pink shrimp relies on the combination of landings and environmental indicators and provides a useful precedent for developing a similar approach for Pacific bonito. The harvest control rule for California pink shrimp seeks to reduce harvest when CPUE is low and environmental conditions are unfavorable as this represents an especially vulnerable coincidence for the stock. This approach works for California pink shrimp because sea level height is a reliable indicator of recruitment conditions, which directly impacts the productivity of the stock. The application of an analogous rule for bonito – where management actions are taken to reduce fishing pressure in years exhibiting both low CPUE and cooler temperatures – is less logical because water temperature changes the availability of the stock rather than its productivity. Thus, in cooler years, CPUE is expected to be lower because the stock is shifted south or offshore, but the stock is not thought to be imperil.

Instead, as suggested in the ESR, the alignment of low CPUE with favorable warm conditions is more concerning, as the stock is not responding as expected and extra precaution is warranted given this uncertainty. Thus, as suggested in the ESR, a dual trigger could be identified where a reference point is exceeded when water is warm (above some temperature threshold) and when CPUE is low (below some density threshold).

The delineation of these thresholds will require (1) the development of a standardized fishery-dependent catch-per-unit-effort index based on CPFV logbooks and (2) the development of an ecologically relevant temperature index. We recommend calculating the CPUE index using recreational CPFV data rather than commercial purse seine data because the CPFV fleet submits logbooks with detailed effort information (**Figure 1**; shows trips but could be angler hours); logbooks are not required for the commercial purse seine fleet.



A. CPFV landings and effort	**B.** Purse seine landings and effort

Figure 1. Landings and effort in the **(A)** recreational CPFV fleet and **(B)** commercial purse seine fleet. Note that CPFV effort can be computed in angler hours and not just trips.

The delineation of an ecologically relevant temperature index is critical for ensuring that the selected index is a good proxy for the distribution of bonito. This is important because, as was demonstrated in a re-evaluation of the harvest control rule used to manage Pacific sardine (McClatchie et al., 2010), temperature indices may not be correlated with each and may capture different ecological processes (**Figure 2**).

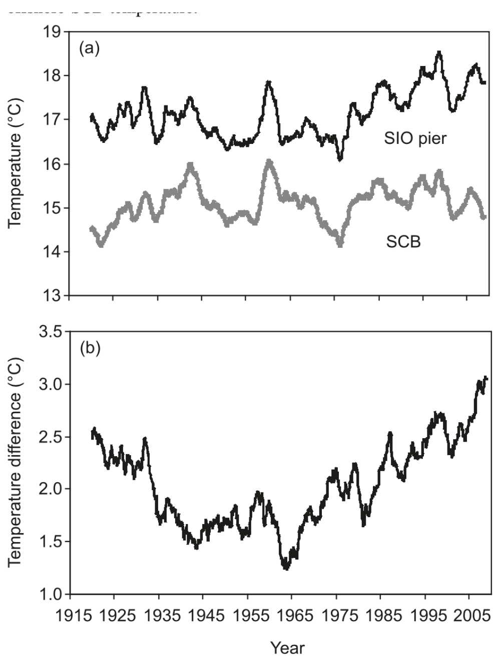
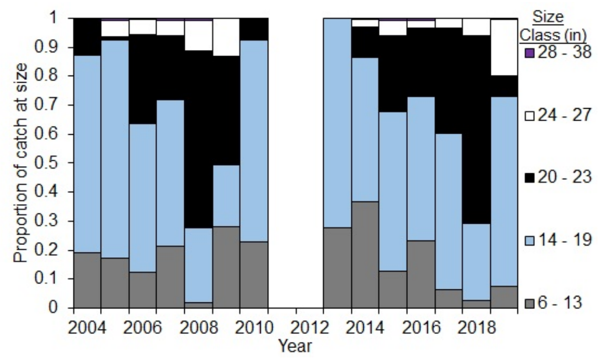


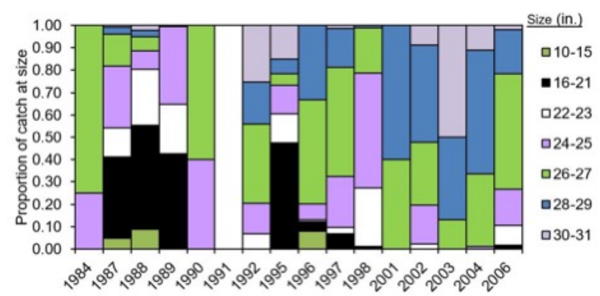
Figure 2. The **(A)** temperature at the Scripps Institute of Oceanography (SIO) pier and the average temperature in the Southern California Bight (SCB); and **(B)** the difference in these temperatures over time. This shows that choice of index matters because they (1) capture different temperature trends and (2) they capture different ecological processes (McClatchie et al., 2010).

3.10.3 Length-based indicators

The ESR also suggests that a limit reference point could be defined by the persistence of the immature bonito in catch compositions. The validity of such an indicator could be examined empirically by examining whether lagged size composition metrics (percent immature, average length, etc.) predict CPUE in subsequent years. It may be worth examining this question with the commercial size composition data as well as the recreational size composition data because the commercial size composition data extend further back in time (**Figure 3**).



A. Recreational CPFV size composition



B. Commercial purse seine size composition

Figure 3. Size composition of the catch from the **(A)** recreational CPFV and **(B)** commercial purse seine fleets.

Similarly, these data could be evaluated using the length-based spawning potential ratio (LBSPR) approach (Hordyk et al., 2015) discussed in *Section 3.2.4* or the length-based indicator approach described in *Section 3.7.2*.

3.10.4 Recommendations

We recommend pursuing both approaches – the CPUE/SST trigger and the length-based analysis – in tandem given that both rely on already existing data rather than new data, are relatively straightforward to implement, and capture different processes that could both indicate need for management intervention. See the sections above for detailed recommendations.

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Appendix A

Identifying species for detailed review

Our second task was to recommend 10-18 ESR species for which we will later provide recommendations for operationalizing sustainability reference points. We posit that the highest priority candidates for such an analysis would be species that (1) are commercially or recreationally important (i.e., not so lightly exploited that they are not at high risk of overexploitation; **Figure S1**) and (2) do not already have an existing Fisheries Management Plan that dictates reference points. This led to the elimination of the following nine ESR species from consideration for the next phase of the project:

- **Existing FMPs:** Pink shrimp, white seabass, market squid, spiny lobster, sheephead
- **Low exploitation:** Pismo clam, Pacific geoduck clam, California grunion, giant/bull kelp

Among the remaining ESR species, we posit that it would be most instructive to select species that represent a diverse array of taxa, that support different fisheries sectors (i.e., commercial, recreational, mixed; **Figure S2**), and that have different levels of data availability (**Figures S3; Table S1**). We managed this selection by picking the highest volume species within each taxonomic order for non-Perciforms and picking the highest volume species within each taxonomic family for Perciforms. Overall, this resulted in 10 species with the following traits:

- 5 finfish (4 orders) and 5 invertebrates (4 orders)
- 7 commercial, 2 recreational, and 1 mixed fisheries
- 2 data-rich, 5 data-moderate, 3 data-poor

The recommended fisheries and their attributes are provided in **Table S1** and are listed below for reference:

1. Barred sand bass
2. Dungeness crab
3. Kellet's whelk
4. Night smelt
5. Pacific angel shark
6. Pacific bonito
7. Red sea urchin
8. Spot prawn
9. Warty sea cucumber
10. Yellowtail

Supplemental Tables and Figures

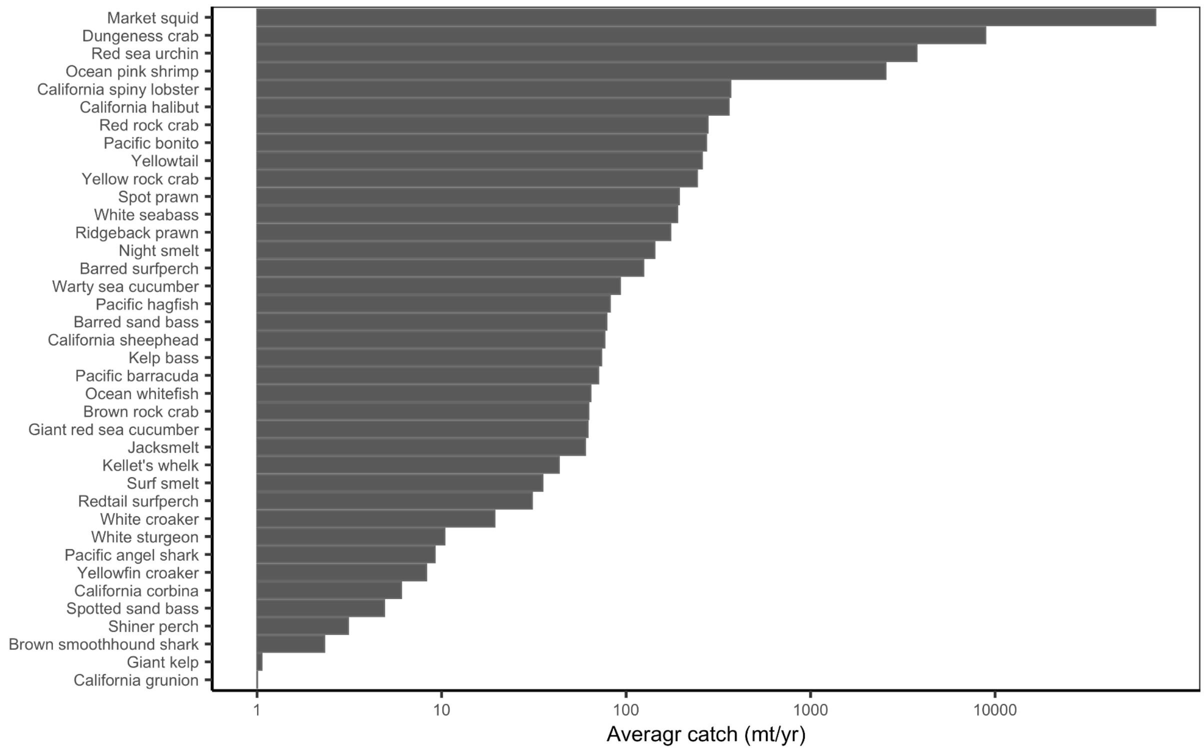

Figure S1. Average catch per year over the last decade (2010-2019) based on commercial catch data from PacFIN and recreational catch data from RecFIN.

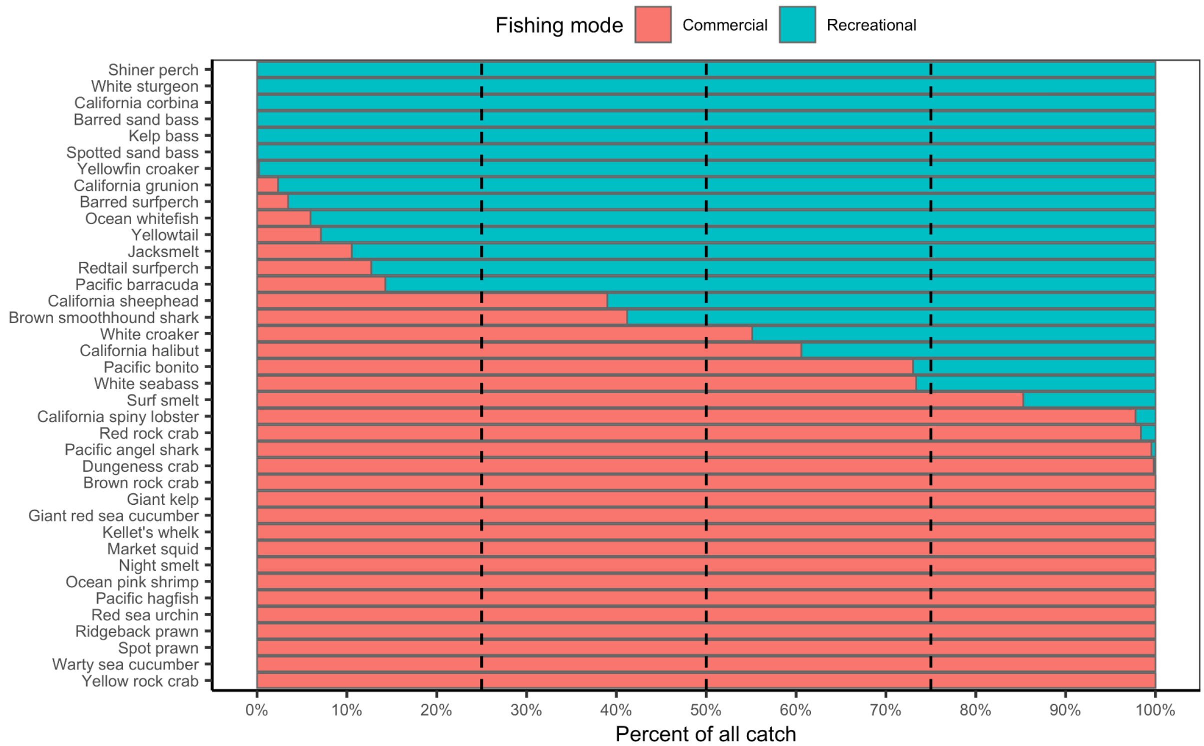

Figure S2. Average percent of total catch attributed to commercial and recreational fisheries over the last decade (2010-2019). Commercial catch data are from PacFIN and recreational catch data are from RecFIN. We classified fisheries with <25% commercial catch as recreational fisheries, fisheries with 25-75% of commercial catch as mixed fisheries, and >75% commercial catch as commercial fisheries.

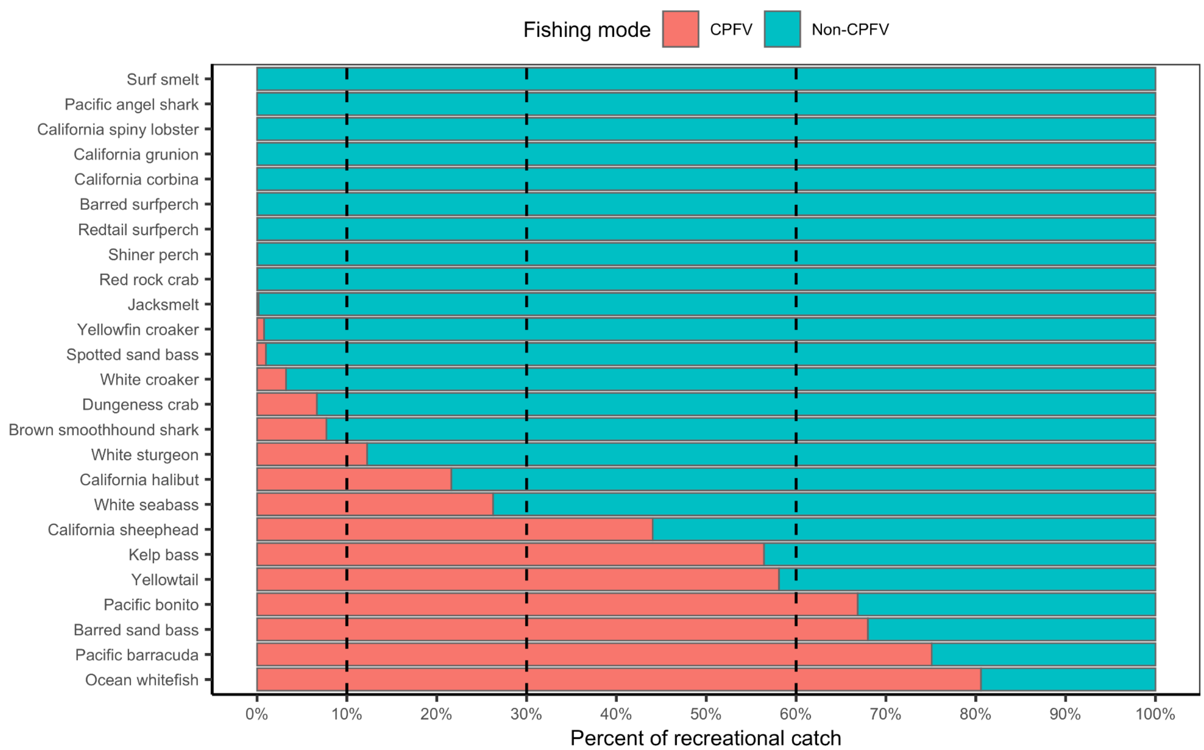

Figure S3. The quality of recreational catch reporting as indicated by the proportion of RecFIN catch that comes from the Commercial Passenger Fishing Vessel (CPFV) fleet, which submits logbooks and is presumed to have good catch reporting, and the non-CPFV modes (e.g., piers, jetties, beaches, private boats) whose catch is statistically estimated through the CRFS program and is therefore presumed to be less accurate.

Table S1. The recommendation for whether to include a species in the next phase of the project and information on data quality.

Common name	Include? (Y/N-reason)	Type	Order	Sector	Comm catch quality	Rec catch quality	CPUE data sources	Data availability
Red sea urchin	Yes-only urchin	Invert	Echinoida	Comm	High	----	CDFW, Reef Check, PISCO, NPS, SB-LTER	Data-rich
Pacific bonito	Yes-only Scombrid	Fish	Perciformes	Mixed	High	High	None	Data-poor
Kellet's whelk	Yes-only mollusk	Invert	Neogastropoda	Comm	----	----	PISCO, VRG, NPS, Reef Check	Data-mod
Yellowtail	Yes-only Carangiform	Fish	Carangiformes	Rec	High	Good	None	Data-poor
Night smelt	Yes-higher value smelt	Fish	Osmeriformes	Comm	----	----	CDFW (2015-16)	Data-mod
Spot prawn	Yes-higher value shrimp	Invert	Decapoda	Comm	High	----	Limited - but SCCWRP, SWFSC	Data-poor
Pacific angel shark	Yes-higher value shark	Fish	Squatiniformes	Comm	High	----	Bell and Tanaka (2008), (CDFW (2018-)	Data-mod
Barred sand bass	Yes-higher value Serranid	Fish	Perciformes	Rec	----	High	GS (1979-2010), CalCOFI (1951-), VRG (1974-), CDFW BRUV/SCUBA (2017-)	Data-rich
Warty sea cucumber	Yes-higher value cucumber	Invert	Aspidochirotida	Comm	----	----	KFMP, PISCO, VRG, Reef Check, SB-LTER	Data-mod
Dungeness crab	Yes-higher value crab	Invert	Decapoda	Comm	High	Low	Limited, but Bay Study, IEP, CalCOFI	Data-mod
California halibut	No-assessment in progress	Fish	Pleuronectiformes	Mixed	High	Fair	CalCOFI, Bay Study	Data-mod
White sturgeon	No-enough non-Perciformes	Fish	Acipenseriformes	Rec	----	Fair	CDFW (1954- partially, 2005- more), Bay Study	Data-mod
Pacific barracuda	No-enough Perciformes	Fish	Perciformes	Rec	High	High	None	Data-poor
Jacksmelt	No-enough non-Perciformes	Fish	Atheriniformes	Rec	----	Low	CDFW, Bay Study, NCFRMP (2007-)	Data-mod
Ocean whitefish	No-enough Perciformes	Fish	Perciformes	Rec	High	High	None	Data-poor
Pacific hagfish	No-enough non-Perciformes	Fish	Myxiniformes	Comm	High	----	None	Data-poor
Surf smelt	No-lower value smelt	Fish	Osmeriformes	Comm	----	Low	Limited - but IEP	Data-poor
Ridgeback prawn	No-lower value shrimp	Invert	Decapoda	Comm	High	----	Limited - but SCCWRP, WCGOP	Data-poor
Brown smoothhound shark	No-lower value shark	Fish	Carcharhiniformes	Mixed	----	Low	Limited, but Bay Study	Data-poor
Kelp bass	No-lower value Serranid	Fish	Perciformes	Rec	----	Good	GS (1979-2010), CalCOFI (1951-), VRG (1974-), NPS (1985-), PISCO (1985-)	Data-rich
Spotted sand bass	No-lower value Serranid	Fish	Perciformes	Rec	----	Low	None	Data-poor
California corbina	No-lower value Sciaenid	Fish	Perciformes	Rec	----	Low	Limited, but GS	Data-poor
Yellowfin croaker	No-lower value Sciaenid	Fish	Perciformes	Rec	----	Low	Limited, but GS (1979-2010)	Data-poor
Shiner perch	No-lower value Embiotocid	Fish	Perciformes	Mixed	----	Low	CDWF, Bay Study, MSI	Data-mod

Giant red sea cucumber	No-lower value cucumber	Invert	Aspidochirotida	Comm	----	----	Limited, but SCCWRP, WCGOP, NPS, PISCO, VRG, Reef Check	Data-poor
Rock crabs	No-lower value crab	Invert	Decapoda	Comm	----	Low	None	Data-mod
California grunion	No-low volume	Fish	Atheriniformes	Rec	----	Low	CalCOFI, Grunion Greeters	Data-poor
Giant kelp and bull kelp	No-low volume	Invert	Laminariales	Comm	----	----	CRANE, PISCO, Reef Check, NPS KFMP, CDFW, satellites	Data-rich
Pacific geoduck clam	No-low volume	Invert	Myoida	Rec	----	----	CDFW (2009-12, 2014)	Data-poor
Pismo clam	No-low volume	Invert	Veneroida	Rec	----	----	Haphazard	Data-poor
White croaker	No-higher value Sciaenid	Fish	Perciformes	Rec	High	Low	CDFW, GS	Data-mod
Barred and redtail surfperch	No-higher value Embiotocid	Fish	Perciformes	Rec	----	Low	CDFW, Bay Study, CDFW-PAS	Data-mod
California sheephead	No-FMP exists	Fish	Labriformes	Mixed	Low	Good	NPS KFMP, PISCO	Data-rich
California spiny lobster	No-FMP exists	Invert	Decapoda	Comm	High	Low	NPS KFMP, MPA monitoring	Data-rich
Market squid	No-FMP exists	Invert	Teuthida	Comm	High	----	RREAS, CalCOFI, CWA	Data-mod
Ocean pink shrimp	No-FMP exists	Invert	Decapoda	Comm	High	----	CDFW (1959-1969)	Data-mod
White seabass	No-FMP exists	Fish	Perciformes	Mixed	High	Fair	OREHP (1993-2008, 2012, 2019)	Data-rich