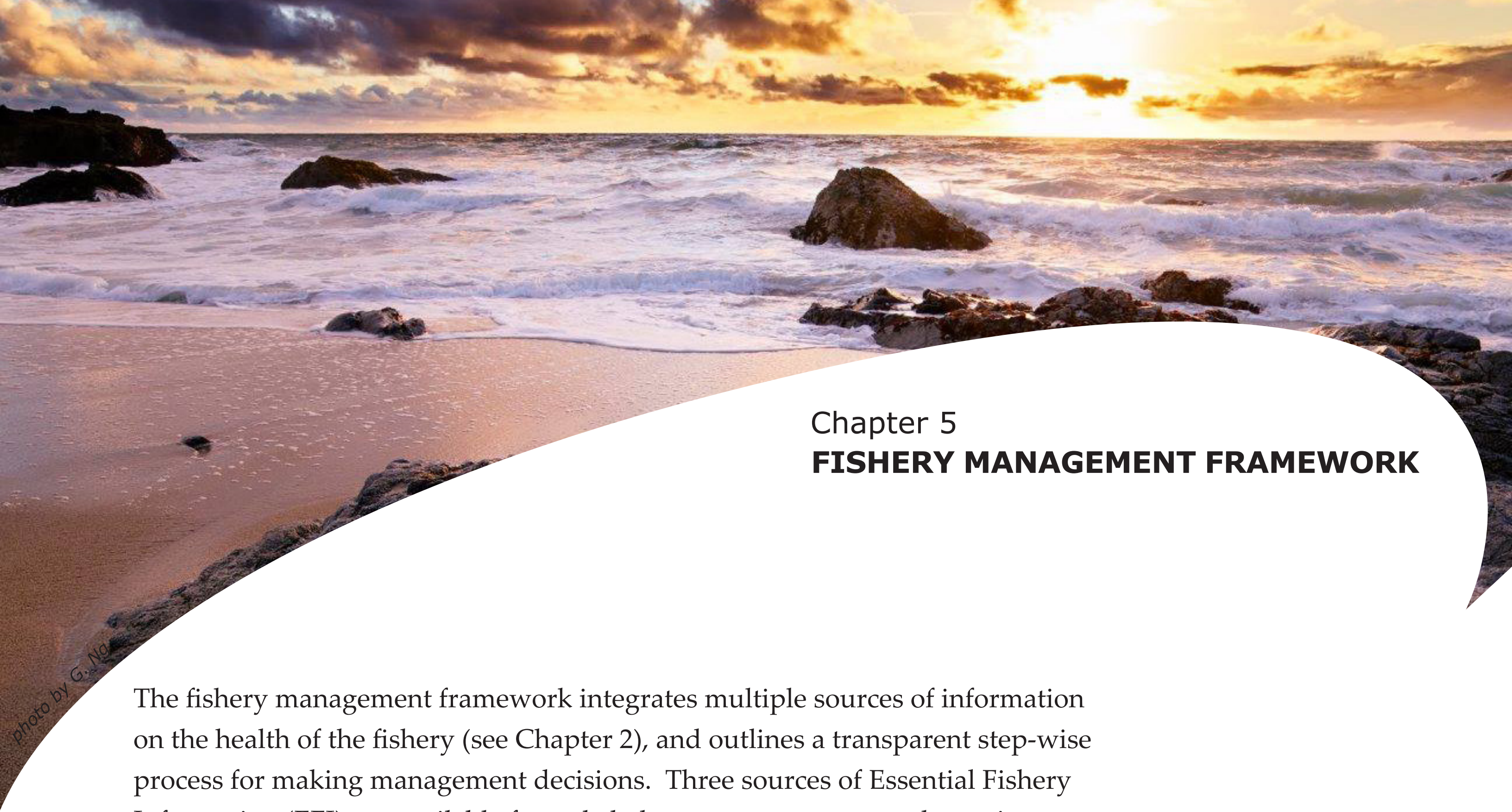


Chapter 5
FISHERY MANAGEMENT FRAMEWORK

The fishery management framework integrates multiple sources of information on the health of the fishery (see Chapter 2), and outlines a transparent step-wise process for making management decisions. Three sources of Essential Fishery Information (EFI) are available for red abalone management: mathematics-based information (theoretical), data-driven information (semi-empirical), and evidence-based research (empirical) (Figure 5.1). Each source is utilized in the management framework to capitalize on its strengths and reduce weaknesses. Theoretical and data-driven sources rely on mathematical models for making broad inferences about the dynamics of the resource, and provide powerful tools for informing coarse management decisions regarding the fishery. Empirical data provide important checks "ground truthing" of the mathematical model results, and give valuable perspectives on the current status of the resource and the fishery relative to historic levels. These multiple sources of information and indicators guide management decisions based on management control rules , defined by either meeting targets or exceeding limits. Targets and limits (reference points) are set to promote the sustainability of the fishery as outlined in the Marine Life Management Act. To accomplish this goal of sustainability, regulations are designed so that fishing mortality plus natural mortality do not exceed reproduction. The resulting regulations operate collectively to promote fisheries and conservation goals, and to maintain a positive and inclusive recreational fishery.

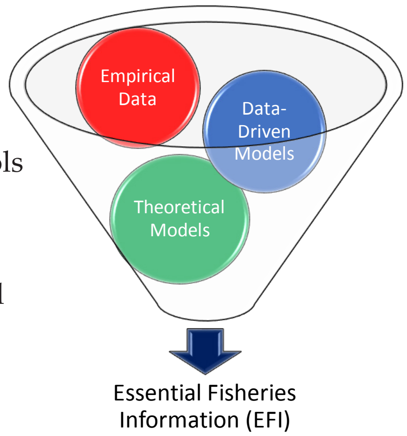


Figure 5.1 The components of essential fishery information (EFI)

Red abalone management in northern California is area-based, and combines traditional (fixed) management tools with adaptive measures that allow responses to small changes in the fishery (Figure 5.2). Emergency management tools may also be applied in response to rapidly developing mass mortality events impacting the fishery. The fixed regulations are applied to the fishery overall, and provide a set of consistent regulations across sites and over time.

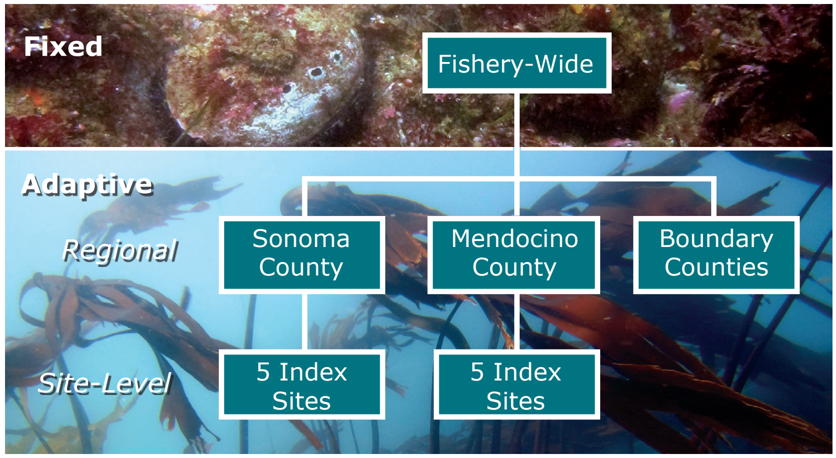


Figure 5.2 Fixed management tools and adaptive measures used in red abalone management

The fixed fishing regulations are key to conserving a portion of the population for reproduction, ensuring fishery sustainability and supporting enforcement. The fixed management regulations are informed by a combination of past fishery management experiences and mathematical models. Adaptive management is applied to subareas of the fishery, so that local changes to the fishery productivity can be responded to at smaller scales. Adaptive management also considers the impact of the environment on the abalone resource, examining temperature, kelp abundance and sea urchin densities. It is well known for abalone and other marine resources that ocean conditions can drive productivity of the resource. These three environmental indicators are used to gauge the productivity of the resource.

The adaptive management portion of the fishery management plan implements a target catch based on extensive knowledge of the productivity of the fishery. The target catch approach can be used as there has been a stable period of time which can be used to inform current management. The target catch is generated each year using this baseline approach, incorporating area specific catch and density information with baseline levels to determine a target catch and catch range. A time series of detailed catch history, open areas in the fishery and density data, as well as environmentally-influenced productivity indicators are used to characterize the expected productivity of the fishery for each subarea.

5.1 Fixed Management

The fixed regulations are a key feature of the red abalone management plan, protecting particularly important segments of the population from fishing pressure to enhance fishery productivity and sustainability. The goal of this management is to allow fishing of only surplus abalone production, to ensure continued sustainability of the fishery. Outputs of mathematical models, compared to informative reference points for productivity, are used to guide the selection of the fixed management regulations (see Chapter 4). Evidence from southern California shows that while a strategy of minimum size limits maintained 48% of the egg production potential in the population (Tegner et al. 1989), this did not lead to sustainable abalone fishing. Therefore, in northern California, the strategy is to maintain >60% of the egg production potential using a combination of regulations that protect young adult abalone, limit incidental mortality, protect reproductive populations in deep water and in marine protected areas (Leaf et al. 2008). The fixed management tools used for red abalone management in northern California in addition to minimum size limits include gear restrictions (no Scuba) and requirements (abalone irons), marine protected areas (MPAs), and regulations to support effective enforcement (fixed start time, abalone cards and abalone tags) (Table 5.1).

5.1.1 Limitations of Fixed Management

While insights from mathematical models are valuable for broadly informing fishery management, deviations from the assumptions of the models may limit the applicability of the results to current conditions. For example, population models are sensitive to model inputs including growth and mortality estimates. Likewise, the fisheries models assume constant fishing pressure and reproduction across sites and over time, although there is strong evidence that recruitment to

Table 5.1 Fixed (Traditional) Regulations

Minimum Legal Size	7 Inches (178 mm)
	No Scuba
	Abalone Iron
	Fixed-Jaw Gauge
Fishing Refuges	Marine Protected Areas
	Deepwater Reserve (≥ 30 ft.)
Enforcement Support	8 a.m. Daily Start Time
	Abalone Report Cards
	Separate Catches per Fisher

populations differs across years. As the behavior of the fishery and catch change, catch may no longer serve as a good proxy for biomass. Further, these models also do not accommodate the spatial complexity of the abalone populations, which are typically highly aggregated. Changing environmental conditions can also dramatically alter growth, reproduction, and mortality, as well as the spatial distribution and density of populations. If there is widespread abalone natural mortality (mass mortality) and little reproduction then model estimates of fishery productivity may mislead management. Lastly, incidental fishing mortality and illegal fishing mortality may reduce the effectiveness of the size limits examined within the models (Burge et al. 1975, Wyner 1977, Rogers-Bennett and Leaf 2006). In order to minimize possible model limitations and violations of assumptions, the red abalone management plan includes additional information on the current status of the resource and the fishery (ground truthing) and incorporates this into the adaptive portion of the management framework.

5.1.2 Fixed Management Tools

5.1.2.1 Minimum Size Limit

The minimum legal size limit is a foundation of fishery management for red abalone because it provides many years of reproduction before individuals become susceptible to fishing, helping to prevent recruitment overfishing. Size-based population models that quantify the contributions of different size classes to the productivity of the fishery guide the selection of an appropriate size limit (Rogers-Bennett and Leaf 2006, Leaf et al. 2008). The abalone that contribute the most to the productivity of the fishery are 5.9 – 7.0 inches (150 – 178mm), highlighting the need to protect this size class from fishing mortality. The minimum legal size limit of 7 inches (178mm) allows abalone to reproduce for six years on average before entering the fishery (Rogers-Bennett et al. 2004, Rogers-Bennett et al. 2007). Adopting a 7-inch size limit for the red abalone fishery promotes abalone productivity while also enhancing the success and enjoyment of fishing for abalone. More than 40% of the abalone taken in the fishery range in size from 7– 8 inches. In northern California, this minimum size limit, combined with additional fixed and adaptive regulations, has supported long-term sustainability of the abalone fishery and provided fishing opportunities for diverse fishers for many years. However starting in 2014 there have been extreme adverse environmental conditions impacting abalone resources.

5.1.2.2 Gear Requirements

The gear requirements applied to this fishery help to reduce incidental mortality of legal and sublegal-sized individuals due to fishing activities. Capturing abalone by prying them off the rock may result in incidental mortality, if the abalone foot is damaged, because abalone have no blood-clotting mechanisms. Historically, incidental mortality has been estimated from abalone creel survey data to be at least 3% of the catch (Burge et al. 1975). Incidental fishing mortality results in higher mortality within the abalone population than is reported by the catch, and negatively impacts productivity.

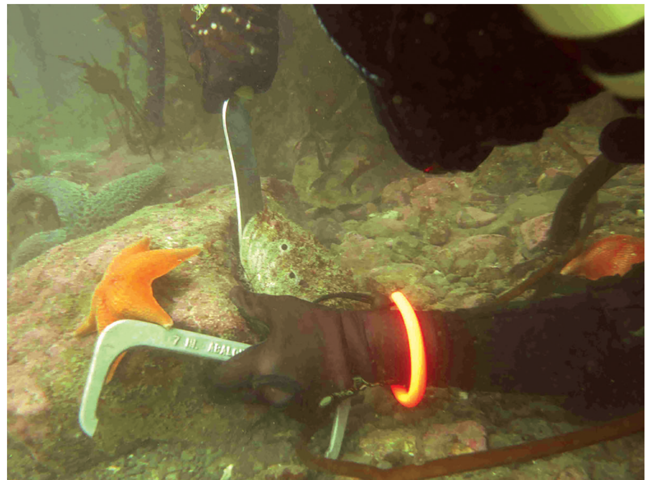


Figure 5.4 Diver pries a red abalone from a rock using an abalone iron, fixed-jaw gauge in hand. *CDFW photo*

Abalone irons and gauges are required fishing gear to ensure that only legal-sized abalone are removed from the rocks, with minimal damage. The required gauge measures the minimum legal size with fixed jaws, and must be carried at all times while abalone fishing (Figure 5.4). The abalone iron must be blunt and wide to reduce injury to the abalone. Fishers are required to only remove legal-sized abalone from the rocks, and to keep all abalone they catch. Abalone fishing activities must cease once the daily bag limit and possession limits are reached. Estimating the size of the abalone prior to pulling it from the rock is important for enhancing the productivity of the fishery by maintaining strong protection for the sublegal-sized abalone. Similarly, replacing one legal-sized abalone with another larger abalone (high grading) is not allowed so that incidental mortality of legal-sized abalone is minimized.

5.1.2.3 Gear Retrictions: No Scuba

Fishery productivity may also be enhanced by protecting reproductive populations in deep water (>30 ft. (9.1m) depths). Prohibiting the use of scuba protects deep-water abalone stocks from high fishing pressure, by effectively limiting abalone fishers to breath-hold diving and rock picking methods of fishing (Figure 5.5). Most divers only fish in water <30 feet. The resulting

Figure 5.5 Fishers must hold their breath when diving for abalone. No scuba gear may be used. *CDFW photos*

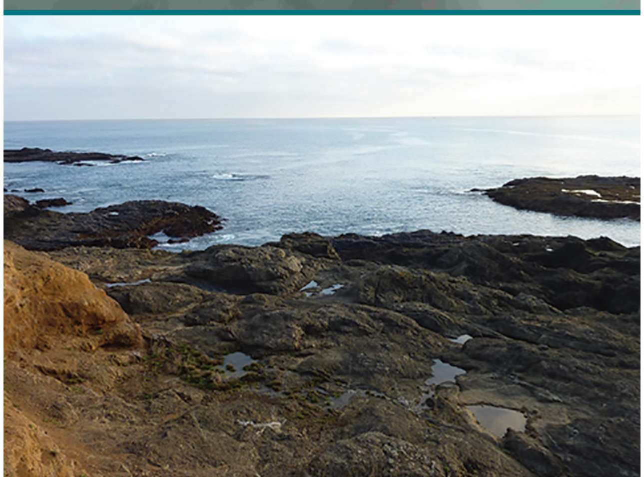


Figure 5.6 The Point Cabrillo area, now a state marine reserve, was protected for many years before MPA designation. *CDFW photos*

deep-water refuge protects red abalone along an interconnected network of deep habitats spanning the entire length of the abalone fishery in northern California. During baseline conditions (2003-2007), approximately one third of the abalone stock was protected in this deep-water refuge, contributing juveniles to the population through reproduction. Reductions in the density of the abalone stock in the deep-water habitats reduces the productivity of the stock. Likewise, large-scale movement of adults from the deep into shallow habitats reduces the effective level of protection from fishing pressure.

5.1.2.4 Marine Protected Areas

Marine protected areas (MPAs) also contribute to fishery productivity by protecting abalone within discrete areas, including shallow habitats where abalone are generally more abundant. As part of the Marine Life Protection Act (MLPA 1999), a network of MPAs was established within the red abalone fishery in 2010 (north-central) and 2012 (north), expanding the number of sites previously protected as MPAs (Figure 5.6). Abalone fishing is prohibited in an MPA, unless otherwise stated. Some of the MPAs permit the take of abalone, so that the percentage of the coast that is closed to abalone fishing is approximately 16% (see Chapter 4). Protection of abalone inside the MPAs allows males and females to grow large without being susceptible to the fishery and the increased reproduction from these large abalone help promote the sustainability of the fishery. While these populations are protected from fishing pressure, harmful environmental

Figure 5.7 Wildlife officer checks abalone fishers during a creel survey to ensure they are in compliance with the law. *CDFW photo*

conditions or disease could impact abalone densities and limit the contribution of abalone inside the MPAs to the productivity of the fishery.

5.1.2.5 Regulations Supporting Enforcement

A number of management tools and regulations aid effective enforcement of abalone fishing. The aim is to reduce illegal take that can damage fishery productivity. Simplified uniform regulations, as well as clear records of each person's catch (abalone report card), allow wildlife officers to quickly and effectively check the compliance of fishers (Figure 5.7). The adoption of a uniform start time of 8 AM for the entire fishery reduces confusion and allows clearer identification of violations. Report cards and abalone tags are powerful tools to track the daily and annual catches, as well as the dates and times that each abalone was caught. To further aid enforcement, each fisher is required to keep their abalone separate from others in their party (in the water and onshore), so that abalone belonging to one person are not co-mingled with another. Fishing for another person "dry sacking" is strictly prohibited. With these regulations, wildlife officers are better able to enforce regulations.

5.2 Adaptive, Area-Based Management

The adaptive management framework responds to changes in county- and site-level fishery dynamics and tracks fluctuations in current stock conditions. The adaptive portion of the plan takes into account the quantity and quality of

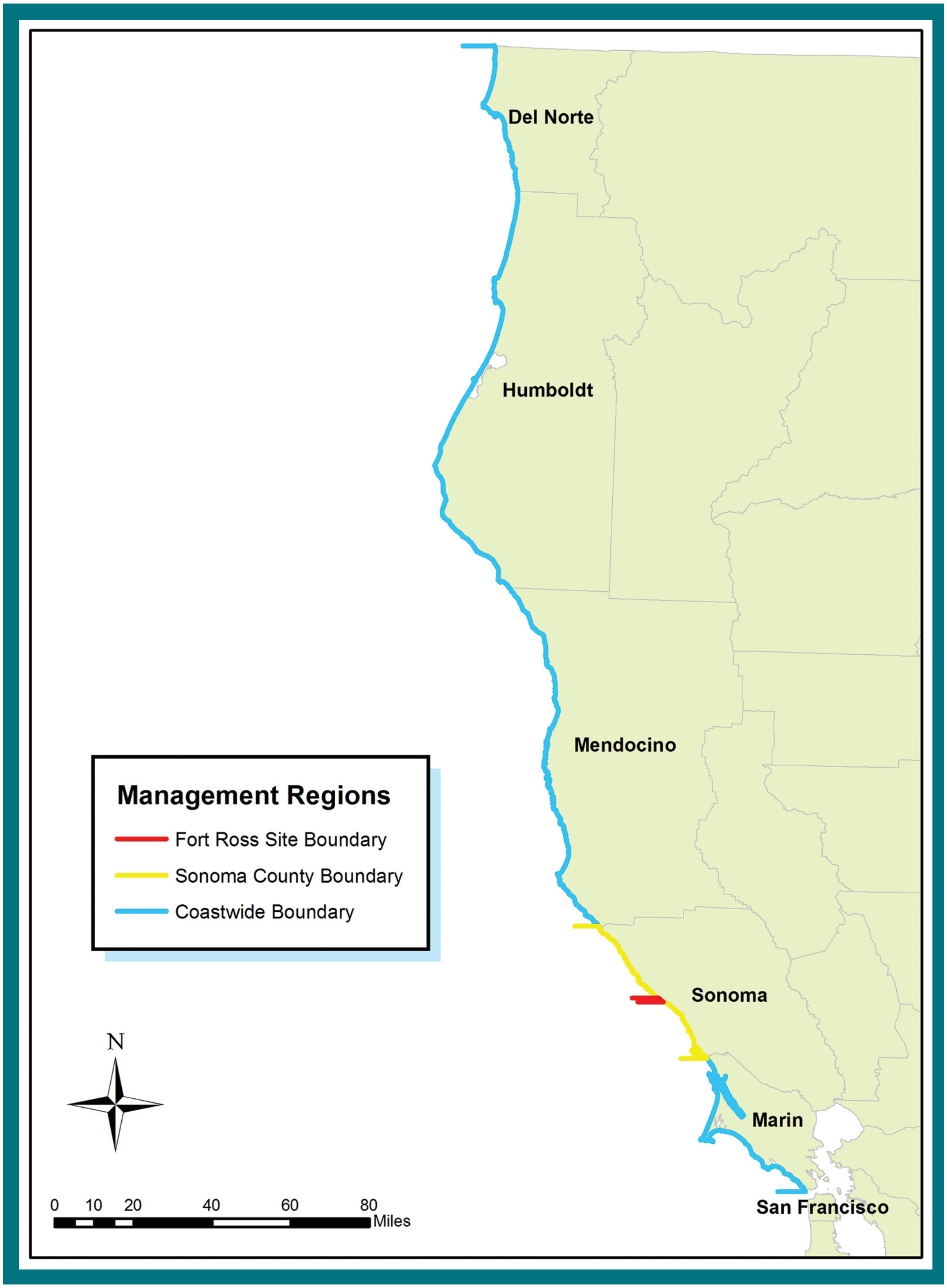


Figure 5.8 Levels of area-based management

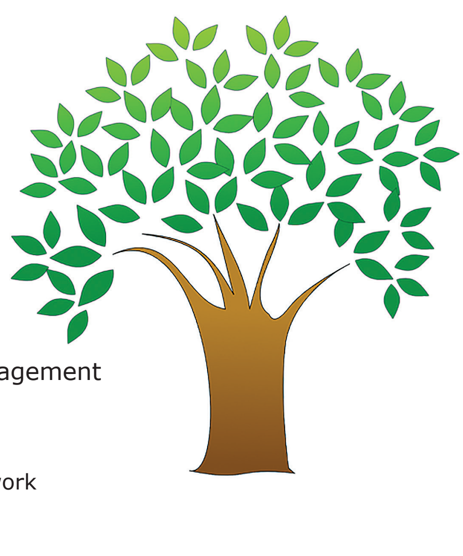
abalone in each area and translates this information from multiple indicators into area based target catches and catch ranges. The season length or daily and annual bag limits are adjusted by area to guide the actual catch toward the target catch which reflects the productivity of the area. Three regions are specified based on historic catch and resource status – Sonoma County, Mendocino County, and Boundary counties (includes Marin, Humboldt, and Del Norte). Dividing the fishery into subareas enables management to be more responsive to local conditions that impact abalone productivity (Figure 5.8).

Sonoma and Mendocino counties have high quality abalone habitat with numerous coastal access points, and have historically contributed >95% of the fishery catch. Because Sonoma and Mendocino counties provide the majority of the catch in the fishery, and represent the core of the abalone population, management of these regions requires the greatest consideration (see 5.3 Core Region Management). Recent mortality events (2011 – see Chapter 4: Harmful Algal Blooms) have impacted the two core counties differently, so that area-based management at the county-level is warranted. The abalone habitat in the Boundary Region is more sparse, with much of the coastline consisting of sandy beaches, salt marshes, and lagoons. Abalone populations in this Boundary Region have low abalone population abundances, although individual abalone may be large in size. Fishing effort in this fishery management plan for the Boundary Region is maintained at low levels as long as the core populations in Sonoma and Mendocino counties remain robust (see Section 5.4).

The adaptive management approach uses fine and coarse tuning to manage the fishery, with the goal of keeping it within the target catch range depending on the dynamics stock (Figure 5.9). One of the primary goals of the adaptive

Fine Tuning

- Compare target catches to actual catch
- Tracks small changes in resource status
- Frequent updated data on catch and resource status
- Automatic pre-determined minor management responses
- CDFW Director initiated management action



Coarse Tuning

- Compare past and current target catches
- Responds to large changes in resource status
- Frequent updated data on catch and resource status
- Initial response automatic, followed by assessment and FGC full rulemaking management process

Figure 5.9 Decision Tree Framework

management is to minimize large disruptive regulation changes to the fishery, instead promoting consistency by "fine-tuning" management regulations only when necessary. The "fine-tuning" mode adopts minor changes to regulations temporarily, and only if the catch exceeds the target range in a given year. Management responds incrementally when the catch exceeds an established broad target catch range, ensuring that regulations remain as long as the fishery performs according to expectations. If large changes in the condition of the stock warrant more substantial actions, then the management strategy will shift to a "coarse-tuning" mode. Both of these tuning modes use up-to-date data on the catch and the resource status.

The **decision tree framework** (Figure 5.9), incorporating both tuning modes, outlines the decision making process for adaptive management which is responsive to changes in the resource and the fishery. A decision tree is a step-wise process used to evaluate data (current status and trends) and specify management decisions. Pre-agreed upon **control rules** direct management actions when the data meet or exceed specific **reference points** (triggers) such as those based on target catch.

5.2.1 Adaptive Management Tools

The preferred management tools for the adaptive management response allow rapid implementation and predictable effects. The length of the fishing season, annual limit, and daily bag and possession limits may be adjusted with minimal administrative delays. These traits make them ideal for "fine tuning" adjustments to the fishery. Small adjustments to the fishing season and annual limit will be used to slightly increase or decrease the catch, whereas adjustments to daily bag and possession limit, as well as to the numbers of report cards sold, may provide a more "coarse-tuning" management option when larger changes to the catch are needed to keep the fishery sustainable. Unsustainable fishery catch levels may occur with a sudden influx of fishers, changes in the efficiency of fishing practices (e.g. new technology), or natural impacts to the abalone populations.

5.2.1.1 Fishing Season

The fishing season is a management tool that spreads out fishing effort across the season to avoid a derby style fishery with crowds of fishery participants

Figure 5.10 Australia's derby-style abalone fishery, West Coast Zone of Western Australia. The fishery is open for one hour on five Sundays each year. *photo by A. Rowland*

all required to fish on the same days (Figure 5.10). The fishing season has historically been open for seven months, April - November excluding July. The spring months offer opportunities to access the abalone during extreme low tides, and typically see the greatest effort for the year. The closure during the month of July limits effort during the busy summer months, and allows for spawning. Season length adjustments would limit fishing as needed, and would apply across all regions.

5.2.1.2 Annual Bag Limit

The annual (season) bag limit is set so that recreational fishers collect abalone for personal consumption only, and allows equal opportunity for fishers to catch abalone throughout the season. The annual limit also provides the most predictable effect on the catch because it imposes a cap on the total number of abalone that may be removed from the fishery. The “fine-tuning” management mode will incrementally adjust the annual limit by county when needed to accommodate changes in the regional fishery productivity and fishery participation.

5.2.1.3 Daily Bag and Possession Limit

The daily limits allow equal opportunity for fishers to catch and possess abalone each day, spreading out fishing opportunities over multiple fishing trips. This also helps to minimize derby-style fishery dynamics. The daily possession limit is equal to the daily bag limit to encourage immediate consumption, minimize stockpiling and illegal commercialization (selling recreational catch). Adjustments to the daily limits would apply fishery-wide as an option for “coarse-tuning” management.

5.2.1.4 Report Cards

Fishery participants are required to purchase and return an abalone report card each year making the cards a useful tool for enforcement and fishery management. Fishers are required to fill in information on their catch tracking 1) number of abalone taken, 2) date and 3) location. Cards are used by enforcement to ensure daily and annual bag limits are being followed. Card data are also used to estimate catch and effort per site per year. Historically, punch cards have been open to everyone to purchase leading to an unrestricted open access fishery. Limiting the number of abalone report cards sold is a tool that may be used to manage the number of fishery participants. Adjustments to the number of report cards sold as well as selling regional or site specific report cards can be used to manage fishing effort and fishery area access.

5.2.2 Core Region Management

The decision tree framework guiding the management decisions for the two core regions (Sonoma and Mendocino counties) relies on the calculation of region-specific target catch ranges. The target catch represents the expected level of fishing in the region during a given year that promotes sustainability. Baseline fishery catch and abalone population density data inform the initial target catch values for each county to be adjusted by current conditions. Current conditions are characterized by site access relative to baseline and measures of productivity (i.e. abalone density, environmental conditions). Upper and lower limit reference points (target catch ±25%) are calculated each year and are compared with the actual catch values for that year to determine if management action is needed. The target catch is updated annually using the most recent regional catch data, changes in access to the fishing grounds (e.g. site openings or closures), and changes in the productivity of the stock based on recent density surveys. The target catch range is designed to be wide enough so that management is not sensitive to minor fluctuations in the fishery, thereby promoting more consistent regulations through time.

The use of the target catch range in the decision tree allows management to track the productivity and effort within each county and to tune the regulations proactively. Fine tuning allows for changes in the fishing season and annual limit which can adjust fishing proactively curtailing or increasing fishing before it goes outside the target catch range. The catch for each county is tracked separately, with distinct target catch ranges calculated. While most management actions will be implemented at the county level, some of the management responses to one county will influence actions taken in the other county, to accommodate impacts from effort shift.

5.2.2.1 Baseline Catch and Density

The average baseline catch provides the foundation for calculating the target catch reference points (Figure 5.11). The baseline period for the catch occurred between 2002 and 2006, when the fishery was stable and abalone report cards provide reliable data for generating catch estimates. This stable baseline time period in the early 2000's also overlaps with the baseline years of abalone density survey data for the fishery (2003-2007). During this time period, there were no large scale impacts to abalone survival or productivity and the fishery was stable (Appendix A).

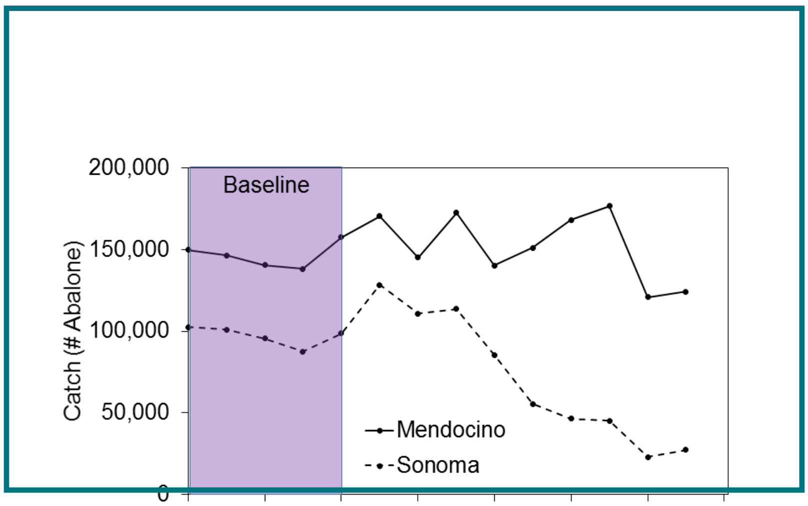


Figure 5.11 Baseline red abalone catch for Mendocino and Sonoma counties

The estimated baseline catch for the fishery as a whole averaged 254,206 abalone per year (Sonoma – 97,102; Mendocino – 146,428). The estimated baseline density for the fishery as a whole averaged 0.63 abalone / m^2 across the eight index sites, with similar values between the two counties. If no changes occurred to the fishery productivity, access, or participation, then the regional target catch ranges would be maintained at baseline levels. This is the expected fishery production of these two regions.

5.2.2.2 Target Catch Calculation

The target catch calculation makes adjustments of the baseline catch for each county, based on changes to site access, abalone density, and other productivity indicators (Figure 5.12).

5.2.2.2.1 Access Adjustments

When access to fishing changes from the baseline (e.g. opening or closing sites), the **target catch** will be adjusted based on the estimated contributions of those sites to the catch during the baseline period (Table 5.2). For example, if a site is closed to fishing due to the establishment of an MPA, the average catch for the site prior to closing will be used to calculate the baseline adjustment. If only a

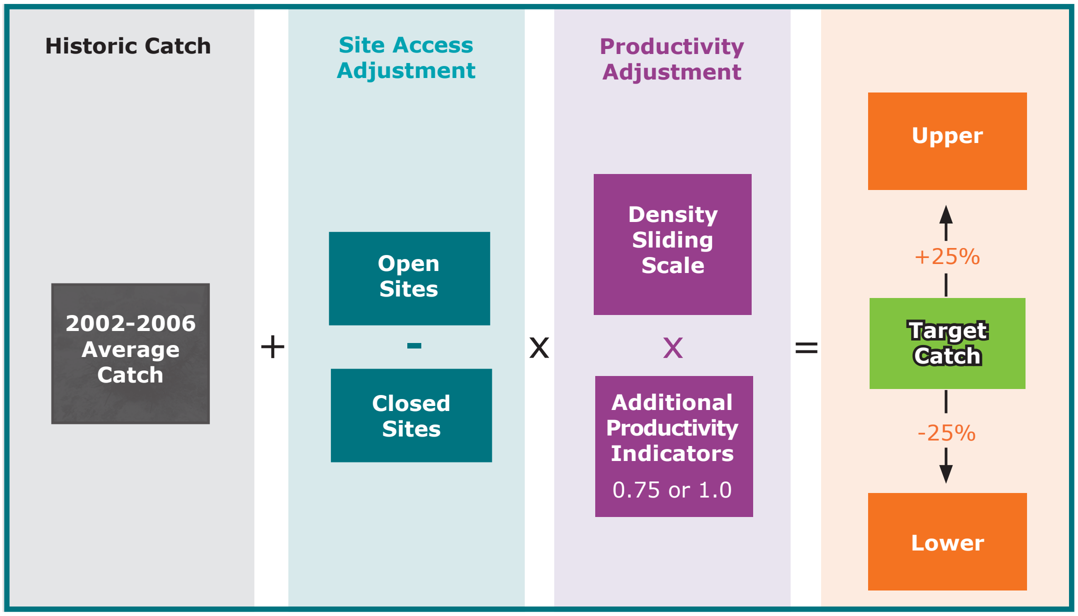


Figure 5.12 Target Catch Calculation Flow Chart

portion of the site closed, then the contribution of the closed area to baseline will be estimated by subtracting the site catch following closure from the baseline average. If an index site is closed due to insufficient abalone densities, then the baseline catch associated with that index site will be used (Table 5.2). If a site is re-opened to fishing, the target catch will be increased according to the average baseline catch from that site (2002-2006). For sites that are newly opened, without prior catch data, baseline catch data from neighboring, comparable sites will be used to estimate the potential catch in the new site.

In Mendocino County, the baseline catch was 146,428 abalone (see above) however, the Marine Life Protection Act (MLPA) process established a network of Marine Protected Areas (MPAs) which closed some areas to the abalone fishery, in 2010 and 2012. Sites where red abalone fishing access changed from baseline conditions due to MPA adoption include Usal, Kibesillah, Point Arena Lighthouse, and Saunders Reef. These areas accounted for an average of 3,595 abalone per year in the catch during the 2002-2006 time period. Mitchell Creek in Mendocino County was opened to recreational red abalone fishing in 2006, increasing the catch potential by an average of 3,145 abalone per year (average for 2007 - 2013). The baseline catch of 146,428 was adjusted by these minor changes in access in Mendocino County for 2017 and so the revised baseline is 145,979 abalone/year.

In Sonoma County, the baseline catch was 97,102 abalone (see above) however, MPAs were established in the North Central coast region in 2010. The sites where red abalone fishing access changed from baseline conditions due to MPAs in Sonoma County include Stewarts Point, Rocky Point, Horseshoe Cove, Fisk Mill Cove, and Bodega Head. For Fisk Mill Cove and Bodega Head, the sites were only partially closed to abalone fishing. The adoption of MPAs in Sonoma County decreased the baseline catch by a total of 8,788 abalone/year. In addition to the MPA adoption, Fort Ross was closed by the Fish and Game Commission in 2014 due to low population densities following a Harmful Algal Bloom which killed thousands of red abalone. The contribution of Fort Ross to the Sonoma County baseline catch was 35,565 abalone per year. The baseline catch of 97,102 was adjusted by these major changes in access in Sonoma County for 2017 and so the revised baseline is 52,749 abalone/year.

Table 5.2 Changes to baseline catches due to MPAs

County	Site	Catch Contribution
Mendocino	Usal	-69
	Kibesillah	-1,237
	Mitchell Creek	3,145
	Caspar Cove	0
	Point Arena Lighthouse	-1,076
	Saunders Landing	-1,212
	SUBTOTAL	***-449***
Sonoma	Stewarts Point	-1,385
	Rocky Point	-281
	Horseshoe Cove	-1,822
	Fisk Mill Cove	-4,867
	Bodega Head	-433
	SUBTOTAL	***-8,788***

5.2.2.2.2 Density Adjustments

Following the access adjustment, the target catch for each county is further adjusted to reflect the most recent average densities observed at the index sites. Catch is related to local density with higher-density populations having more productive catch histories than lower-density populations (see Appendix B). Historically, a shift in the fishery catch dynamics occurred at population densities below 0.5 abalone/m^2 which is defined as the Density Target Reference Point. Catches were stable at the index sites with densities greater than the density reference point and declined at those sites when densities fell below the density reference point (see Chapter 3). Density is also a key indicator of reproductive success with higher densities have closer nearest neighbor distances which favors fertilization and reproduction (Figure 5. 13)(see Chapter 3).

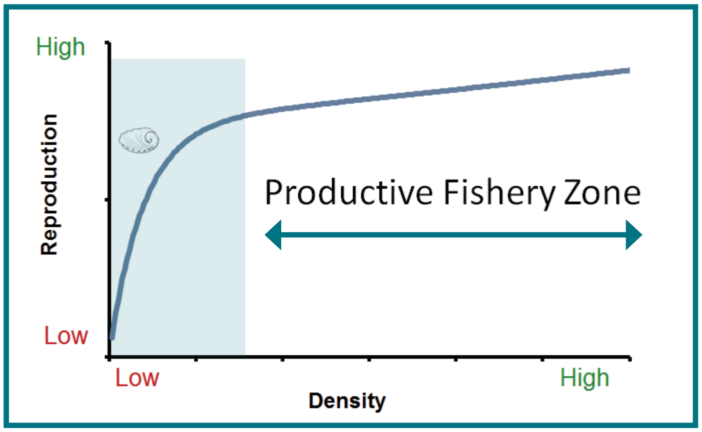


Figure 5.13 Reproduction rate at different levels of density

Density is used to adjust the target catch on a linear sliding scale, allowing for higher catches at densities above the density target and more conservative catches at densities below the density target (see Appendix C). At this key density, the adjustment to the catch is equal to the proportion of the baseline density value. For example, the density target of 0.50 abalone/m^2 is 79% of the baseline density of 0.63 abalone/m^2, so that the corresponding density adjustment to the target catch would be 0.50/0.63 = 0.79. The maximum target catch adjustment based on density is set at 1.20 (for densities ≥ 0.67 abalone/m^2), so that future catch values remain within historically sustainable levels. Given that the target catch range is the target catch ±25%, the maximum adjustment values for the upper and lower target catch range limits are 1.50 and 0.90, respectively.

For populations with densities below the minimum viable population density (MVP ≤ 0.2 abalone/m^2), productivity may be significantly impacted resulting in declining population abundances (see Chapters 3 and 4). Historically areas below MVP have not supported productive abalone fisheries. To avoid MVP levels across a large area of the fishery, a lower limit reference point for the average county densities is set at 0.3 abalone/m^2. This density level is set above MVP to support productive abalone stocks in the core region. If average county densities fall below 0.3 abalone/m^2, then the catch will be set to zero for that county to allow the populations to rebuild. If the density at any one of the index sites falls below 0.25 abalone/m^2, then that site will be closed to allow for recovery (see Sections 5.2.2.4 and 5.2.2.5).

The density adjustment along a sliding-scale is a critical component of the fishery management plan which incorporates density information from the fishing grounds into management. Density is a key feature of the “fine-tuning” management approach which incorporates continuously updated fishery-independent density data into the adaptive management (see Chapter 4). Each year, as resources permit, a subset of the index sites will be surveyed from each of the core counties and those new data will replace the older values in the average density calculation for the region. The average density for each county incorporates all index sites for that region, including any sites that were closed to the fishery due to population impacts (e.g. Fort Ross). Empirical density data from the abalone stocks in the region, rather than theoretical information on the status of the stocks, is used to calculate the regional target catch.

5.2.2.2.3 Additional Productivity Indicator Adjustments

The fixed and adaptive management approaches described above assume consistent productivity of the abalone populations through time. Sustainability of the fishery relies on continued surplus abalone production available for the fishery so that reproduction exceeds fishing mortality plus natural mortality. Because abalone populations are slow growing, with long generation times and it takes many years to reach the minimum legal size, significant changes in the productivity may require substantial adjustments to the target catch. If the productivity of the resource is impacted by environmental conditions, then even high densities of abalone may not produce sufficient juveniles for the future fishery. Therefore, rapid, responsive management actions to large-scale or chronic sublethal effects impacting fishery productivity is critical to minimize overfishing of the resource.

The critical indicators that may have long-term negative consequences on fishery productivity include:

- Regional density of deep-water (>30 foot (10m) depth) abalone populations
- Abalone gonad index (reproductive condition)
- Abalone body condition index (health/mortality)

Lower population densities in deep water than have been present historically represent a substantial reduction in overall fishery productivity. The productivity of ⅓ of the population that are outside of the fishing depths contribute substantially to the overall fishery productivity. If abalone move from the deep into shallow water in search of food this portion of the population will be vulnerable to fishing pressure. Poor reproduction and body condition are

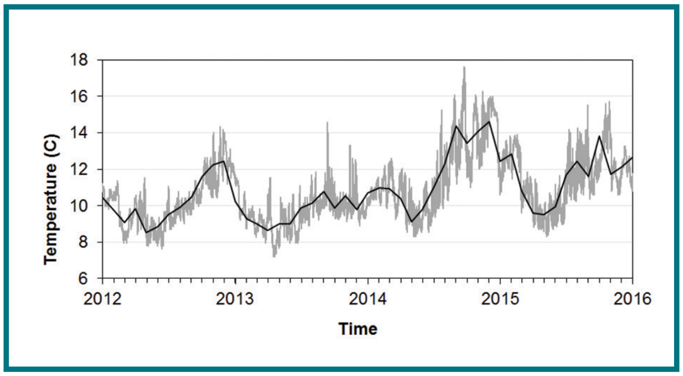


Figure 5.14 Nearshore ocean temperatures at 30 ft. (10 m) in Mendocino County

indicators the abalone are not contributing to fishery productivity.

Reduced gonad and body condition are detectable after one year of chronic impact. Further, abalone recovery requires at least one year of improved environmental conditions. Future fishery productivity is slowed from a combination of poor reproduction and increased potential for natural mortality. The reduction in the generation of young abalone will impact the future fishery. CDFW tracks the average density of abalone in the deep-water refuge at index sites in each county during the annual density surveys. Abalone gonad and body condition indices will be quantified if severe environmental conditions warrant concern. Environmental or ecological factors will trigger spring gonad and body condition assessments including:

- Ocean Temperature – Nearshore ocean temperatures at 30 feet (10 m) in Mendocino County ≥15º C on any day in the previous calendar year (subtidal temperature loggers) (Figure 5.14)
- Canopy-Forming Kelp Abundance – The total area of surface kelp in either of the counties is ≤ 30% of historic maximum extent (CDFW kelp aerial surveys or other comparable remote sensing tools tracking kelp surface area) (Figure 5.15)
- Sea Urchin Density – The combined densities of red and purple sea urchins ≥ 5 urchins/m^2 at any of the index sites (CDFW subtidal ecosystem surveys (≤ 60 foot (20 m) depths) (Figure 5.16)

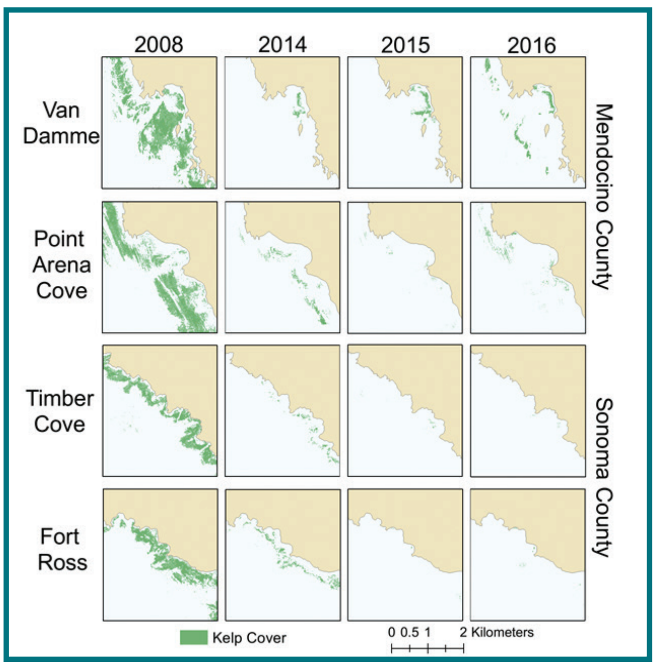


Figure 5.15 Kelp canopy cover from aerial surveys during 2008, 2014-2016

Temperature has direct and indirect impacts on red abalone. Warm water decreases reproduction and increases the metabolism requiring abalone to eat more. Bull kelp (*Nereocystis luetkeana*) is a critical food and habitat resource for the abalone populations and is the foundational canopy-forming kelp forest species in the northern California (see Chapter 4). The density of herbivore competitors such as sea urchins can negatively impact the quantity of food available to support red abalone health and reproduction.

Figure 5.16 Sea urchin barrens with purple and red urchins *CDFW photo*

If gonad and/or body condition are poor (Figure 5.17), in combination with any of these large-scale environmental stressors, then the impact is considered to be chronic and warranting management action. If any one of these three critical indicators exceed threshold levels, then the target catch will be reduced by 10% to reflect the reduced productivity in the fishery based on that indicator. These measures enact a more precautionary approach that is responsive to environmental drivers of abalone populations. Additionally, if all three productivity indicators are triggered, then the catch for that county will be set to zero and re-opening will only be considered when all three productivity indicators are favorable (see Section 5.5). If population conditions indicate higher productivity (deep-water density only), then the target catch levels may be increased by 10% to reflect higher confidence in the future fishery productivity.

Figure 5.17 Poor gonad condition
CDFW photo

The critical thresholds for each of the productivity indicators are:

Deep-Water Abalone Density

- Low productivity indicator: Average deep-water density within a county falls below 0.20 abalone/m^2.

- High productivity indicator: The average density within a county exceeds 0.40 abalone/m^2.

Abalone Gonad Condition

- Low productivity indicator: Average Spring gonad index <100 from ≥60 abalone (≥ 7 inches (178mm)).
    - Sonoma County – Fort Ross
    - Mendocino County – Van Damme State Park
- High productivity indicator – not applicable

Abalone Body Condition

- Low productivity indicator: Greater than 15% of abalone (n ≥ 500 abalone) with observable shrunken foot muscle (Shrinkage Score >0) at county-specific creel survey sites.
- High productivity indicator – not applicable

5.2.2.3 Decision Tree Framework and Management Responses

Management needs to be responsive to the level of change required in the fishery. The decision tree guides the management response so that the magnitude of the response matches the magnitude of the change needed in the fishery. Small adjustments in the catch (fine-tuning) should be made when the fishery overshoots (or undershoots) the target catch range. Larger changes to management (coarse-tuning) are needed when the target catch changes rapidly, by more than 25%, between years. The decision tree outlines the steps that might lead to closing of fished sites and/or closing of the fishery, including severe losses of abalone density or productivity. The decision tree also clearly outlines the conditions that would allow sites and counties to re-open following recovery.

5.2.2.3.1 Fine-Tuning Management

The fine-tuning management approach is used when the abalone resource and the fishery are stable and robust. This approach responds quickly to deviations in catch from the ±25% target catch range with small changes to the season length and the annual limit. The pre-agreed upon management response (increasing or reducing fishing pressure) will be implemented automatically by the CDFW Director with the guidance of Marine Region staff to enable timely action. Management action will be implemented in two phases (Figure 5.18) – short-term temporary season adjustment (immediate season), followed by a standard adjustment of the annual limit by one daily bag limit (following season). If last years region's catch exceeds the target catch range (target catch + 25%), then the current season will close two months earlier than normal. This season length adjustment will be applied across the entire fishery to minimize impacts of effort shift and to support effective enforcement. The following year, the season length will be restored (providing no additional catch exceedance occurred) and the annual limit within the affected county will be reduced by one daily bag limit. If however, last years catch falls below the target catch range, then the current years season will remain open one month later (December open to fishing) than normal (across the entire fishery), and the annual limit will be increased by one daily bag limit the following year.

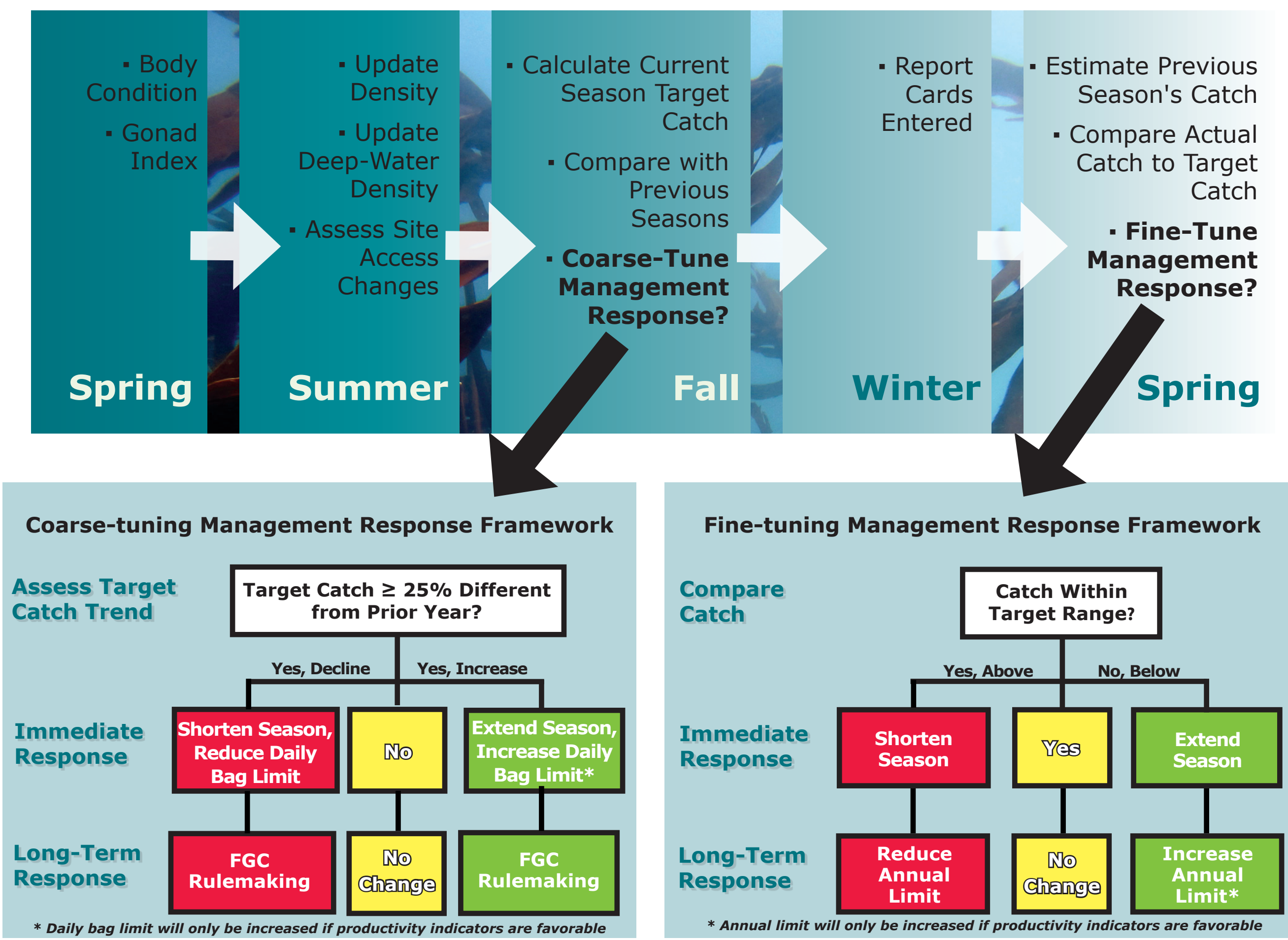


Figure 5.18 Target Catch Calculation Timeline with Coarse- and Fine-Tuning Management Response Frameworks

5.2.2.3.2 Coarse-Tuning Management

The “Coarse-Tuning” management approach applies when larger changes to the abalone resource or fishery are observed, requiring more substantial adjustments to fishing effort (Figure 5.18). This approach will be engaged when the target catch changes by >25% between years. A combination of automatic short-term measures implemented by the CDFW Director (for the following season) and long-term measures adopted by the FGC through a standard rulemaking process (implemented for the season following the short-term response) will be used to adjust fishing effort with the public as a partner in this process. The short-term actions will be to adjust the season length by one month and to change the daily bag limit by one abalone across the entire fishery. This action across all regions will minimize impacts of effort shift and support effective enforcement. Marine Region staff will provide recommendations to the FGC for additional management actions to most effectively respond to the status of the stocks, taking into consideration the economic costs and impacts to recreational fishing opportunities.

5.2.2.4 Region Closure

If the target catch for one of the two core regions is set to zero, then that region will be closed immediately. Management actions may also be recommended for the remaining open region to minimize impacts from effort shift. The daily bag limit will be reduced by one abalone (following season) while the Marine Region staff present additional management options to the FGC in a standard rulemaking process. If both of the core regions are closed to fishing, then the boundary region will also close. The target catch for one region may be set to zero if 1) average densities across all index sites in that region <0.3 abalone m^2 or 2) all three low productivity indicators are triggered (Figure 5-19).

5.2.3 Boundary Region Management

Catch histories in the boundary region including the counties of Marin, Humboldt, and Del Norte show that these areas have historically had low productivity, with populations dominated by a few large individuals. The Boundary Region productivity is low in part due to low kelp abundance, high silt inputs from freshwater sources and limited prime rocky habitat. This region has sustained low levels of abalone catch through time and have consistently contributed less than 6% of the catch since 2002. The total baseline catch for these

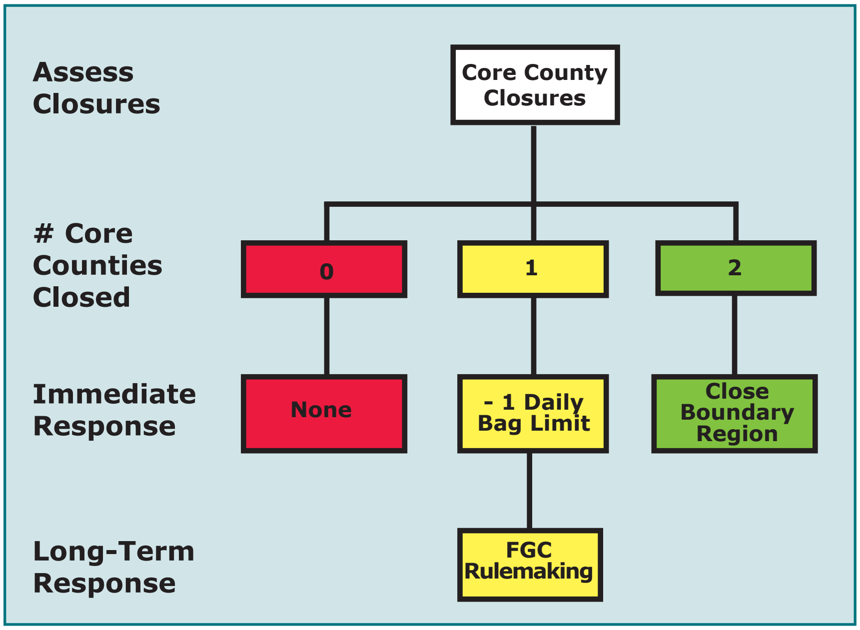


Figure 5.19 County Closure Management Response Framework

areas from 2002-2006 was approximately 10,000 abalone. Fishery catch data will continue to be monitored to assess the need for regulation changes for this region. If the catch in any year exceeds the baseline catch level of 10,000 abalone by 25%, or comprises >10% of the total fishery catch, then additional surveys will be conducted at key fished sites within these counties to inform management recommendations to the FGC.

The annual catch limit for the Boundary Region is set at 6 per year to maintain baseline catch levels. This catch level represents the status quo for this region as 99% of the all fishers catch 6 or fewer abalone per year in this region. Of the fishers active in this region, more than 80% catch 6 or fewer abalone per year throughout this region.

5.3 Emergency Management Scenarios

A number of abalone mortality factors may dramatically impact red abalone population dynamics in northern California. These impacts can rapidly decrease the density of red abalone available to the fishery through mass mortality events. For potentially lethal impacts that might occur in a short amount of time

Figure 5.20
A harmful algal bloom off the Sonoma Coast in 2011 resulted in mass mortality of abalone.

(< three years), a rapid density assessment will be conducted to inform fishery management. In addition, samples from dead and dying invertebrates (e.g. abalone, mussels) will be collected to aid in identifying the source of mortalities and any human health risks. Environmental and man made sources of mass mortalities across large spatial scales include, but are not limited to:

- Harmful Algal Blooms (Figure 5.20)
- Abalone Disease (Figure 5.21)
- Low Oxygen (Figure 5.22)
- Oil Spill (Figure 5.23)

If a large number of dead abalone are observed at any one site or multiple sites, then the affected sites will be closed and rapid abalone density assessments relevant to the mortality source (if known) will be conducted.

Rapid assessments will focus on counts of abalone within transect survey areas, including numbers of dead (freshly empty shells and decomposing abalone), dying (too weak to adhere to the reef), and living abalone.

Habitat assessments (algal cover and substrate) and abalone size measures will not be included in these rapid surveys unless these factors are also expected to be relevant to the source of the mortality or its effects. If the source of the mortality is unknown, more assessments may be warranted to determine the cause. Additional sampling will be conducted depending on the suspected source of the mortality (see below). The fishery sites will remain closed until assessments have been completed.

5.3.1 Harmful Algal Bloom

Harmful algal blooms (aka red tides) have had strong negative impacts on red abalone survival in northern California and around the world (see Chapter 4). One genus of dinoflagellate (one-celled alga) is of particular concern (*Gonyaulax* spp) since it appears to have been the causative agent responsible for a mass mortality of abalone in Sonoma County in 2011. If the genus *Gonyaulax* dominates (>50%) water plankton samples at routine monitoring sites within the fishery range, then additional plankton samples from the fishing grounds will be collected to identify the species and track the progression of the bloom(s) that may impact abalone mortality. If members of the public observe and report dark red or black looking water consistent with a harmful algal bloom, then samples will be collected and assessed.

5.3.2 Abalone Disease

Abalone diseases have also negatively impacted fisheries in California and around the world (see Chapter 4). In particular, the bacterial disease Withering Syndrome is of high concern in California. Other abalone diseases due to viruses have also been identified as major concerns. Any mass mortality event of red abalone in northern California will trigger collection of abalone tissues and may include water samples for PCR detection of known disease

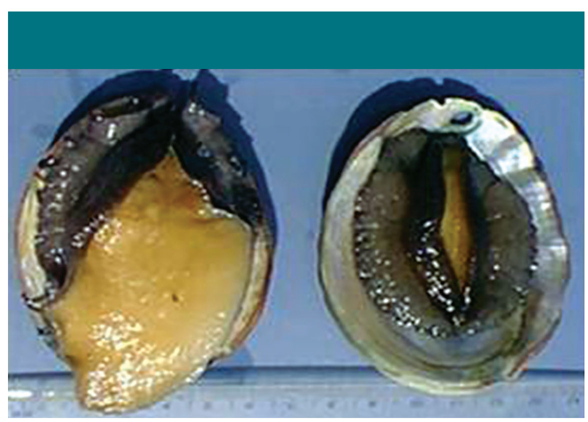


Figure 5.21 Healthy (left) and diseased (right) red abalone *CDFW photo*

Figure 5.22 Oxygen logger deployed on the fishing grounds *CDFW photo*

causing agents such as viruses and bacteria.

5.3.3 Low Oxygen Events

Large-scale low oxygen events have the potential to create dead zones in marine ecosystems (Diaz and Rosenberg 2008). The Eastern Pacific including northern California is a region prone to low oxygen water that can be upwelled near the coast (Helly and Levin 2004), especially during the spring when strong winds drive upwelling of low oxygen water close to shore (see Chapter 4). CDFW and other institutions maintain oxygen sensors at shallow subtidal sites at 30 feet (10 m) on the abalone fishing grounds that will inform additional monitoring actions in the case of a low oxygen event. If low oxygen conditions are recorded by these sensors, then additional abalone and water samples will be collected to monitor oxygen levels at the affected and unaffected sites.

Figure 5.23 Beach closure due to oil spill *CDFW photo*

5.3.4 Oil Spill

Oil spills can also have devastating impacts on marine life in the nearshore environment. California has had a number of large oil spills near San Francisco, from tanker collisions to failures of pressurized oil wells (see Chapter 4). An oil spill impacting the two core abalone fishery regions could have a major impact on the red abalone resource. If a major spill occurred then the rapid response abalone density assessments may use drop cameras to monitor conditions, if the water quality proved unsafe for divers. Water samples, as well as tissue samples, from impacted and healthy abalone in the area will also be collected and samples will be taken in cooperation with Oil Spill Prevention and Response Teams.

5.4 Fishery Reopening Following Recovery

Environmental conditions will need to be favorable for abalone as a prerequisite to reopening of a closed fishery. The environmental conditions need to be conducive to population productivity and increases in density (>0.25 m^2). Citizen science may play an important role in collecting data used to inform reopening, environment, density and size frequency (see Section 5.2.2.7).

As populations become more productive during the recovery phase densities will increase (>0.25 m^2). The fishery can be reopened as the population enters the rebuilding phase. Recovery and rebuilding will be based on data showing increases in densities at the site and fishery levels. Reopening densities are designed to be sufficiently above closure thresholds to avoid fishing driving the densities immediately back below closure. The thresholds for reopening are set at moderate densities at least 50% above closure thresholds.

Recovery will also be based on evidence of small and large abalone within the size frequency distributions of the population. These data will be collected by CDFW, partners or the public at popular dive sites within the fishing grounds. Small individuals (sublegals) will ensure the future of the fishery and legal size abalone will provide for robust reproduction. During and after recovery the populations may be comprised of numerous small individuals. Reproduction will be more limited in a recovering stock compared with a mature stock due to smaller-sized adult abalone producing fewer gametes, and greater distances between individuals. In contrast, a mature stock (>0.5 m^2), under normal environmental conditions, has the highest levels of reproduction that promote the most surplus production to support a vigorous and sustainable fishery. Due to the slow growth of abalone, stock recovery may take over a decade (Rogers-Bennett et al. 2004, Rogers-Bennett et al. 2007).

Fishery rebuilding is most robust when it is supported by multiple areas with healthy reproductive populations. Productive populations in neighboring areas to the closures may contribute to rebuilding of nearby stocks through limited larval or juvenile dispersal. Reopening of areas may occur at multiple levels within the fishery depending on the geographic extent of the closure. The

smallest closure area is the site level. Larger scales include one region or the fishery as a whole . Threshold levels for reopening areas depend on the spatial scale of closure and are informed by baseline conditions.

5.4.1 Site Reopening

A series of three criteria will be examined to determine the eligibility of a site within an otherwise open region to reopen. Prior to conducting population surveys at the site, broad-scale environmental indicators (e.g. kelp forest health and water quality) for the region must be favorable for abalone productivity. If environmental conditions are good, then the size distribution of abalone within the site will be assessed to ensure sufficient availability of legal and sublegal individuals. Sublegal and legal-sized abalone in combination are capable of producing the large quantities of gametes supporting robust stock rebuilding. Sublegal abalone are important to ensure future fishery sustainability. The size distribution (of at least 500 abalone) is similar to baseline conditions (2003-2007), including at least 40% legal-sized adults and at least 30% sublegal animals (See Chapter 4 for Size frequency of sublegal and legal size abalone). If these early indicators suggest that the stock is recovering, then density surveys will be conducted to assess the strength of the recovery. The overall site density trigger for reopening a site is 0.4 abalone / m^2. The site reopening threshold density is set 60% above the site closure trigger (0.25 abalone/m^2) to buffer against site re-closure. If only one site in a region is closed, then that site may reopen once all of the reopening criteria are achieved. If all sites in a region are closed, then reopening would be based on the regional reopening criteria and more caution is needed and the criteria for reopening a region will be applied.

5.4.2 Region Reopening

When a region or the entire fishery is closed then abalone health indicators need to be favorable before reopening criteria of abalone size and density are applied (see Section 5.2.2.5). First, the environmental conditions including seawater temperature, kelp abundance, and sea urchin abundance need to be favorable before the abalone productivity indicators are assessed. Red abalone gonad index in the closed region will be compared with historic gonad data (See Section 5.2.2.5). Size criteria from DFW or partner groups will then be examined at multiple sites within the closed region. The combined size-frequency

distribution of all surveyed sites within the region will be assessed to ensure sufficient availability of legal and sublegal individuals (see Site Reopening). If both health and size criteria are achieved, then dive surveys will be conducted to examine overall density and the deep-water density. Density surveys will be conducted at each index site in the region (N=5) using the rapid assessment survey protocol to obtain updated density estimates throughout the region. If the deep water density is ≥ 0.20 abalone/m^2, and the overall density is ≥ 0.45 abalone/m^2, then the region will reopen. The region reopening threshold density is set 50% above the region closure trigger to buffer against region re-closure following fishing. In an open region, site closure harvest control rules apply (site closure at <0.25 abalone m^2). A new target catch will be calculated with the most up-to-date information. A suite of fishery management options (e.g. annual limits, daily limits, etc) will be analyzed and presented to the FGC for consideration and adoption upon reopening the region.

5.4.3 Fishery-Wide Reopening

If all areas of the fishery are closed, then the regions will reopen when the average density across the index sites in each core region (Mendocino and Sonoma) is ≥ 0.45 abalone/m^2. The fishery-wide reopening threshold density is set at regional levels to buffer against fishery re-closure. Once both the core regions have reopened (see Region Reopening) then the boundary region may reopen. A new target catch will be calculated for each of the core regions with the most up-to-date information and the suite of management options to attain the target catches will be determined through the regulatory process with the FGC. Once the target catches have been established for the core regions, then the boundary region will be reopened and managed as a percent of the total catch (See Section 5.2.3 Boundary Region Management).

5.4.4 Reopening Scenarios

The MLMA mandates management that optimizes fishery productivity and sustainability (FGC 7055a). Fishing too soon during a rebuilding phase may jeopardize and could slow recovery. The priority for management during the recovery phase, prior to reaching broad scale reopening densities, is to focus on supporting robust recovery by excluding fishing. During the rebuilding phase, at moderate densities, a limited level of fishing may be allowed. Limited fishing levels are designed to allow for a sustainable fishery with the continued rebuilding of the stocks. Management following rebuilding, when stocks reach maximum productivity (>0.5), will optimize fishing and economic opportunities.

These reopening criteria ensure that stocks will be able to produce and sustain target catches. To illustrate possible regional and fishery wide reopening scenarios, minimum target catches for reopening along with possible management options are presented (Table 5.4). A minimum target catch for a region can be calculated assuming all the reopening criteria have been met and there are no changes in access. Assuming the region has met the reopening densities, the minimum target catch for Sonoma County would be 59,000 abalone per year. The minimum target catch in Mendocino County would be 92,000 abalone per year. The minimum target catch for the fishery as a whole including the boundary region would be 161,000 abalone per year. Different combinations of report card sales with annual and daily bag limits can be combined to explore the tradeoffs in reaching the reopening target catch. Managing the number of abalone report cards sold during the rebuilding phase allows fewer participants to take more abalone per year. Once the fishery reopens, a full rulemaking and FGC process will be undertaken to put forward a range of management options available to reach the target catch. After the first fishing year following reopening is completed, the actual catch will be compared

Table 5.4 Fishery reopening scenarios presenting minimum target catches for reopening and possible management options

Regions Open	Target Catch	Boundary Region	Annual Limit	Daily Limit	# Report Cards
Sonoma Only	59,000	Closed	2	2	30,000
			6	3	10,000
			12	3	5,000
Mendocino Only	92,000	Closed	3	3	30,000
			9	3	10,000
			18	3	5,000
All Regions	151,000	10,000	6	3	26,000
			12	3	13,000

with the target catch and the harvest control rules in the FMP will guide future fishery management adjustments.

5.5 Target Catch Evaluation

A Management Strategy Evaluation is an analytical procedure used to assess the performance of the management plan under different fishery scenarios and environmental conditions. In this case, we conduct a Target Catch Evaluation (TCE) to determine when regulation changes may have been triggered in the past (hindcast models) or if the management responses would yield appropriate results under multiple future scenarios (future simulation models). Both hindcast and forecast models may be informative to the management strategy development and selection process.

Hindcast models use data from the actual past fishery dynamics and environmental conditions to evaluate when the management strategy would have triggered management actions. These hindcast model assessments are only possible to conduct for fisheries with many years of historic catch data. For the northern California recreational red abalone fishery, hindcast models are appropriate because there are more than 15 years of available data on the fishery dynamics, including multiple years when one portion of the fishery (Sonoma County) was impacted requiring management actions.

Simulation models on the other hand, rely on the creation of a virtual fishery within which different management strategies may be tested. The strength of these simulated analyses is to compare relative outcomes between different management scenarios. These assessments are most useful for species and fisheries that have well-defined unchanging dynamics. Simulation outcomes should not be interpreted as an accurate forecast of what the fishery will be in 25 years but rather the relative benefits of one management approach compared to another for the model (virtual) population. Simulation models, such as egg per recruit models, of the red abalone fishery in northern California have been used to evaluate the relative importance of deep-water densities and alternative size limits to population productivity (Leaf et al. 2008). Simulation outcomes may be misleading in cases where they are used 1) to predict the future fishery,

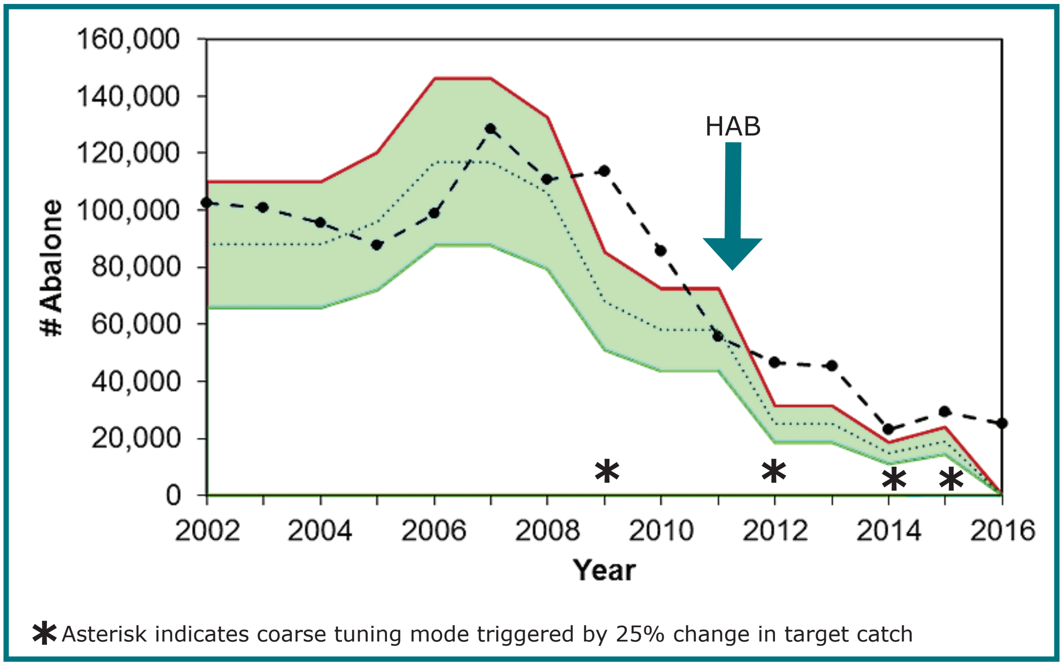


Figure 5.26 TCE model for Sonoma County

2) with highly variable dynamics, 3) with large variations in model input values (growth and survival values)(Nash 1992), 4) with violations of key model assumptions (growing populations, constant reproduction, closed population), or 5) populations experiencing catastrophic events outside the scope of the model.

Simulation modeling of the dynamics of this fishery management plan is problematic because management relies on the comparison between the target and the actual catch. The dynamics of the fishery behavior within different scenarios of resource health and regulations is not well-defined, and is not predictable into the future. Without reliable future catch information it is challenging to assign short- and long-term management responses in the following years to assess long-term sustainability of the resource. Given these challenges and the recent extreme environmentally-driven changes to the abalone growth, reproduction, and mortality estimates, conclusions from forecast models may be overly optimistic.

5.5.1 Hindcast TCE Model

A hindcast TCE model was used to explore the frequency and timing of fishery management responses in the past if the FMP harvest control rules had been

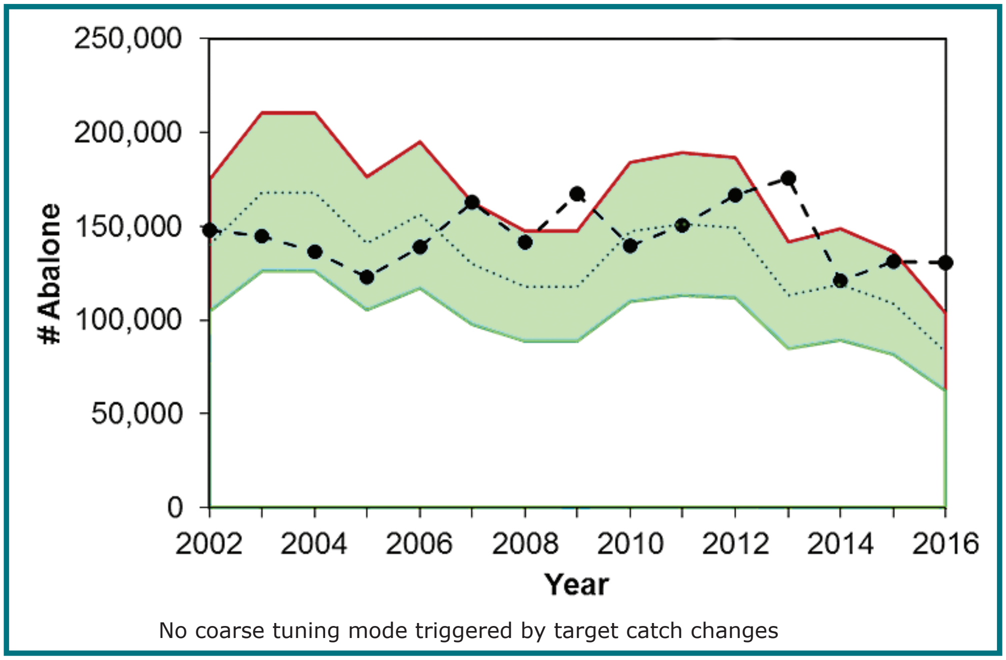


Figure 5.27 TCE model for Mendocino County

applied to the historic fishery (2002-2016). The target catch was calculated for each year and compared with past fishery dynamics to refine the target catch calculation inputs. Familiarity with the past resource health, catch sustainability and management responses provided guidance on the desired timing, magnitude, and location of management actions. The graphs of the TCE model show years when management would be more responsive (narrow target catch range) and when the management changes would be less frequent (wide target catch range).

5.5.2 TCE Model Results

The hindcast model results were examined to determine if the FMP described here would have resulted in management actions at times and places in the past when management was warranted. In other words, do the FMP indicators and decision tree results led to actions when they are needed: does the FMP pass the common sense test. To more closely examine this for the fishery, two TCE models were developed representing each of the two core regions (Figures 5.26 and 5.27). For each year, the actual catch was compared with the target catch range to determine if it exceeded the range triggering a fine-tuning management responses. The target catch was also compared with the previous year's target to determine the

Table 5.5 Red Abalone Management Evaluation Result Table for Sonoma County

Year	Action Recommended	Catch	Target Catch	Lower Limit	Upper Limit	Action
2002	-	102,554	88,000	66,000	110,000	-
2003	-	100,957	88,000	66,000	110,000	-
2004	-	95,602	88,000	66,000	110,000	-
2005	-	87,627	96,000	72,000	120,000	-
2006	-	98,771	117,000	87,750	146,250	-
2007	-	128,239	117,000	87,750	146,250	-
2008	-	110,743	106,000	79,500	132,500	-
2009	Action	113,574	68,000	51,000	85,000	Coarse
2010	Action	85,438	58,000	43,500	72,500	Fine
2011	-	55,560	58,000	43,500	72,500	-
2012	Action	46,568	25,000	18,750	31,250	Coarse
2013	-	45,262	25,000	18,750	31,250	Fine
2014	-	23,062	15,000	11,250	18,750	Coarse
2015	Action	29,064	19,000	14,250	23,750	Coarse
2016	Action	25,123	-	-	-	Closure

need for coarse-tuning management. The resulting management actions and the timing of these actions are summarized in Appendix C, Tables 1 and 2.

In Sonoma County, the actual catch falls within the target catch range in 8 of the 15 years, primarily before 2009. The target catch in Sonoma County was moderately stable around 100,000 abalone per year or higher during the period from 2002 to 2008. Coarse-tuning management in Sonoma County would have been triggered during four years – 2009, 2012, 2014, and 2015. Whereas, in 2016, in Sonoma

Table 5.6 Red Abalone Management Evaluation Result Table for Mendocino County

Year	Action Recommended	Catch	Target Catch	Lower Limit	Upper Limit	Action
2002	-	147,976	140,000	105,000	175,000	-
2003	-	144,841	168,000	126,000	210,000	-
2004	-	136,201	168,000	126,000	210,000	-
2005	-	122,562	141,000	105,750	176,250	-
2006	-	139,007	156,000	117,000	195,000	-
2007	-	162,796	130,000	97,500	162,500	Fine
2008	-	141,282	118,000	88,500	147,500	-
2009	-	166,929	118,000	88,500	147,500	Fine
2010	-	139,304	147,000	110,250	183,750	-
2011	-	150,421	151,000	113,250	188,750	-
2012	-	166,892	149,000	111,750	186,250	-
2013	Action	175,340	113,000	84,750	141,250	Fine
2014	-	120,905	119,000	89,250	148,750	-
2015	Action	131,428	109,000	81,750	136,250	-
2016	Action	130,585	83,000	62,250	103,750	Fine

County, all three productivity indicators were impacted due to multiple years of severe environmental stress, which would have led to the closure of the region (target catch of zero). The timing of these coarse-tuning triggers is consistent with the timing of known past severe challenges to the fishery, providing confidence that the target catch calculation in the FMP will initiate timely and responsive management decisions (Table 5.5).

In Mendocino County, the target catch was more stable, hovering around 140,000 abalone per year from 2002 to 2014. With the wide range around the target catch the actual catch remained inside the target range in most years, indicating few changes in regulations with infrequent fine-tuning management responses (Table 5.6). The actual catch falls within the target catch range for 11 of the first 15 years with the deviations in 2007, 2009, 2013 and 2016. Heavy fishing pressure at the Stornetta Ranch site, briefly opened between 2006 and 2010, caused the mismatch observed in 2007 and 2009. In 2013, effort shift to Mendocino County following the harmful algal bloom in Sonoma County resulted in the actual catch exceeding the target prior to the adoption of regulation changes in 2014. Productivity indicators for Mendocino County were impacted in 2016, triggering reductions in the target catch. These reductions in the target catch occurred despite the actual catch remaining high given the increased vulnerability of the abalone to the fishery as the abalone moved toward food resources in shallow water. This year 2016, is an example of where the actual catch went outside of the narrow target catch range warranting management actions.

The results of the TCE show that the use of target catch would have detected known past impacts to the fishery, and would have generated meaningful target catch ranges and management responses when it was appropriate. The TCE shows the narrowing of the 25% ranges around the target catch during declining years (e.g. 2012-2016) which is a desirable feature allowing management to be more proactive (triggered more often) when abalone stocks are impacted. Conversely, during periods with robust stock health (e.g. 2002-2006), the 25% buffer around the target catches is wide so that management is less reactive to fluctuations in the actual catch.

There are multiple desirable features of the HRC rules that are highlighted with the results of the hindcast TCE. First, in time periods when catches are stable, few management changes are prescribed such as in Mendocino County from 2002 to 2014. Second, when there are impacts to productivity, the target catch is responsive, as seen after the harmful algal bloom in Sonoma County. Third, as target catches are reduced the target range narrows leading to more proactive management when needed for impacted stocks. Finally, the HCRs comprised of multiple indicators of stock health informing the target catch ranges when then give clear guidance for when to reduce fishing pressure on impacted stocks to promote recovery.

5.6 Management Summary

The red abalone management framework is strongly science-based, deriving information from multiple sources and is poised to trigger management actions when necessary to maintain this unique and productive fishery for future generations. This plan includes fixed management strategies to maintain a portion of the population for reproduction outside of the fishery in the deep water reserve and inside Marine Protected Areas. The population accessible to the fishery is actively managed using an adaptive approach which is sensitive to local changes in both fishing area access as well as abalone density. The plan takes an innovative approach for how to incorporate the productivity of the stocks, regardless of the density, given the current environmental conditions. Further, the plan provides a means to respond to potential catastrophic abalone mortality scenarios and outlines management actions needed for these impacts making it climate ready. This comprehensive management plan takes advantage of the suite of EFI data streams available including fine scale knowledge of catch and uses them in the management decision making process to help sustain this world class recreational red abalone fishery.

5.7 References

Burge, R., S. Shultz, and M. Odemar. 1975. Draft report on recent abalone research in California with recommendations for management. Department of Fish and Game:1-67.

Diaz, R. J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321:926-929.

Helly, J. J., and L. A. Levin. 2004. Global distribution of naturally occurring marine hypoxia on continental margins. Deep Sea Research Part I: Oceanographic Research Papers 51:1159-1168.

Leaf, R. T., L. Rogers-Bennett, and Y. Jiao. 2008. Exploring the use of a size-based egg-per-recruit model for the red abalone fishery in California. North American Journal of Fisheries Management 28:1638-1647.

Nash, W. J. 1992. An evaluation of egg-per-recruit analysis as a means of assessing size limits for blacklip abalone (*Haliotis rubra*) in Tasmania. Pages 318-338 in S. A. Shepherd, M. J. Tegner, and S. A. Guzmán del Próo, editors. Abalone of the world: Biology, fisheries, and culture. Fishing News Books, Cambridge, MA.

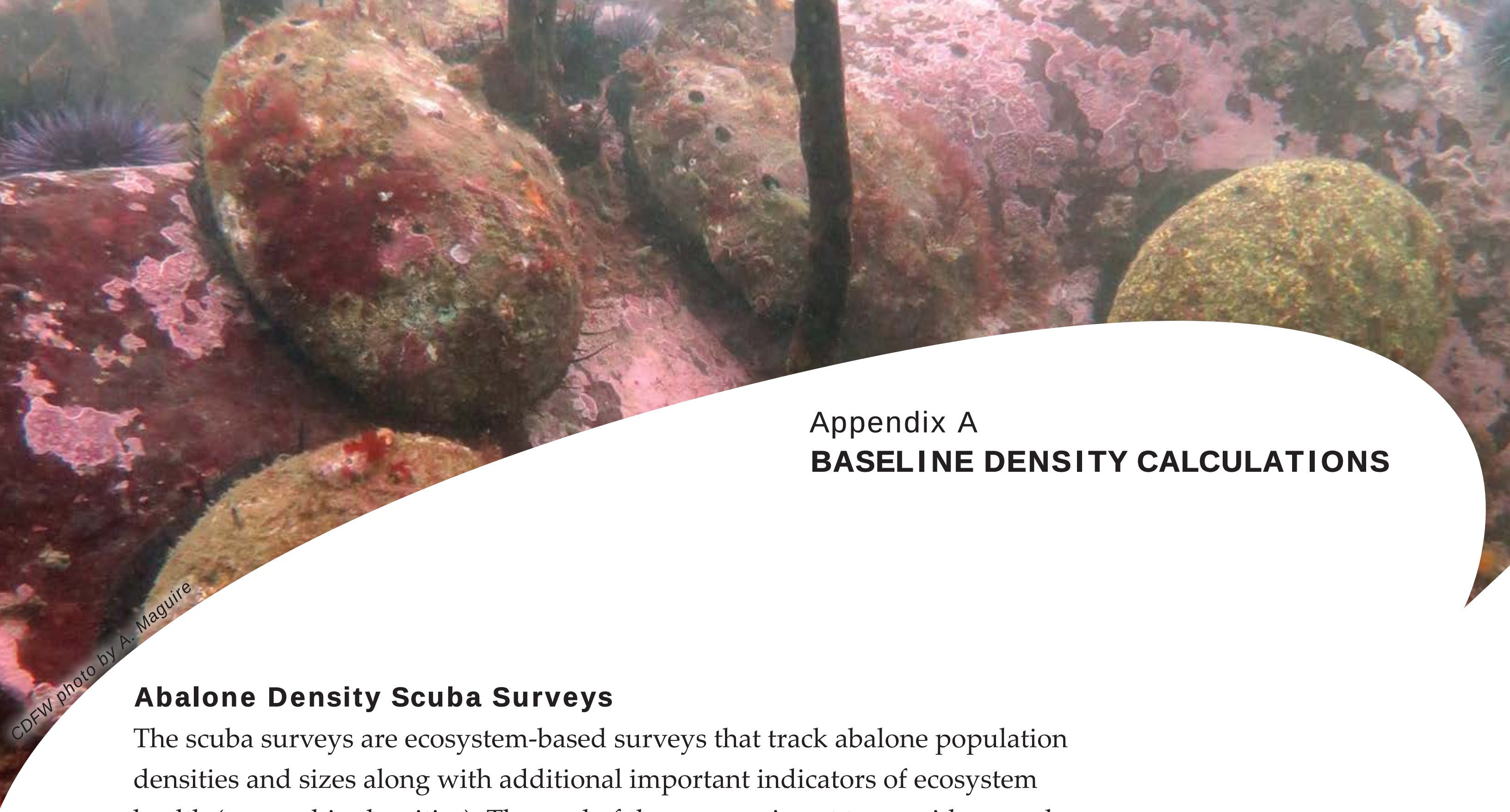
Rogers-Bennett, L., R. F. Dondanville, and J. Kashiwada. 2004. Size specific fecundity of red abalone (*Haliotis rufescens*): Evidence for reproductive senescence? Journal of Shellfish Research 23:553-560.

Rogers-Bennett, L., and R. T. Leaf. 2006. Elasticity analyses of size-based red and white abalone matrix models: Management and conservation. Ecological Applications 16:213-224.

Rogers-Bennett, L., D. W. Rogers, and S. A. Schultz. 2007. Modeling growth and mortality of red abalone (*Haliotis rufescens*) in Northern California. Journal of Shellfish Research 26:719-727.

Tegner, M. J., P. A. Breen, and C. E. Lennert. 1989. Population biology of red abalones *Haliotis rufescens* in southern California and management of the red and pink *Haliotis corrugata* abalone fisheries. Fishery Bulletin 87:313-340.

Wyner, A. J., J. E. Moore, and B. Cicin-Sain. 1977. Policies and management of the Californian abalone fishery. Marine Policy 1:326-339.



Appendix A
BASELINE DENSITY CALCULATIONS

Abalone Density Scuba Surveys

The scuba surveys are ecosystem-based surveys that track abalone population densities and sizes along with additional important indicators of ecosystem health (e.g. urchin densities). The goal of the surveys is not to provide a random sample to describe the density of the population as a whole (or biomass estimate), but rather to examine important fished sites over time to determine if abalone fishing is sustainable at those sites.

Depth is an important covariate for abalone density in this population and many other abalone populations. Random transects are placed within four depth strata, divided equally within 0m to 18m depths to capture differences in red abalone densities by depth. Previous surveys determined that red abalone are more abundant in the shallower depth strata. Random placement of transects are used so that the density estimate is representative of the strata within a site overall. The first two shallow depth strata (A) 0 – 4.6 m (1 – 15 ft) and (B) 4.9 – 9.1 m (16 – 30 ft) are within typical recreational free diving fishing depths. The two deeper depth strata (C) 9.4 – 13.7 m (31 – 45 ft) and (D) 14.0 – 18.3 m (46 – 60 ft) are beyond the free diving capability of most fishers since scuba is not allowed and are considered a refuge from fishing for deep abalone populations (Karpov et al. 1998).

Sea urchin reserves also influence red abalone density through increased competition from red urchin populations. At two sites (Sonoma – Salt Point; Mendocino – Caspar Cove), transect placement is further stratified inside and outside of commercial urchin no-take reserves. The Salt Point urchin reserve expanded in size in 2012 to encompass the full survey site.

Transects (30 x 2m) are placed at pre-determined random GPS coordinates greater than 70 m apart within each index site. Random sampling locations are generated with GIS software (Arc View v 3.2) and Random Point Generator software (RPG v 1.3). The base maps used are USGS topographic maps (datum NAD 1983) with detailed depth information. Once at the random point, dive teams deploy transects along the target depth stratum, generally parallel to shore, within rocky reef habitats. Only emergent abalone were counted and measured, such that all abalone were detected without the use of dive lights or rolling over boulders. The lengths of the first 25 abalone were measured with calipers to the nearest millimeter. A total of 36 transects is targeted for each site, with equal numbers of transects per depth stratum.

Baseline Density Calculations

Abalone densities calculations for a site are estimated by averaging transect densities within a depth stratum and then averaging across the four depths at each site. For sites with commercial urchin reserves, the average density by depth stratum is weighted by the area inside and outside of the reserve. The regional densities for Sonoma and Mendocino counties are calculated by averaging across all five index sites within each county for a total of 10 index sites.

Baseline density are calculated using the above methods, from 8 index sites for the time period spanning 2003-2007. The baseline density result differs slightly from the ARMP baseline (completed in 2005) which only had data from 3 sites available at the time from the earliest surveys (1999-2001). Two minor adjustments are needed to update the FMP Baseline density. First, one site in Sonoma County (Timber Cove 2006) lacked data from the deepest depth stratum in the early years (2003-2007), so data from this depth and site were supplemented by data from the next survey period (2009). Additionally, due to the expansion of the commercial urchin reserve at Salt Point State Park during the MLPA process, the abalone densities from inside the historic reserve were chosen to better represent the baseline for the current condition of the site. The new adjusted baseline density (2003-2007) is estimated to be 0.63 abalone m^2 ($\sigma = 0.17$). The baseline density estimate is used as a point of reference for development of the target catch calculation evaluation (see Appendix C Figure 1) and plays a minor role in the FMP.

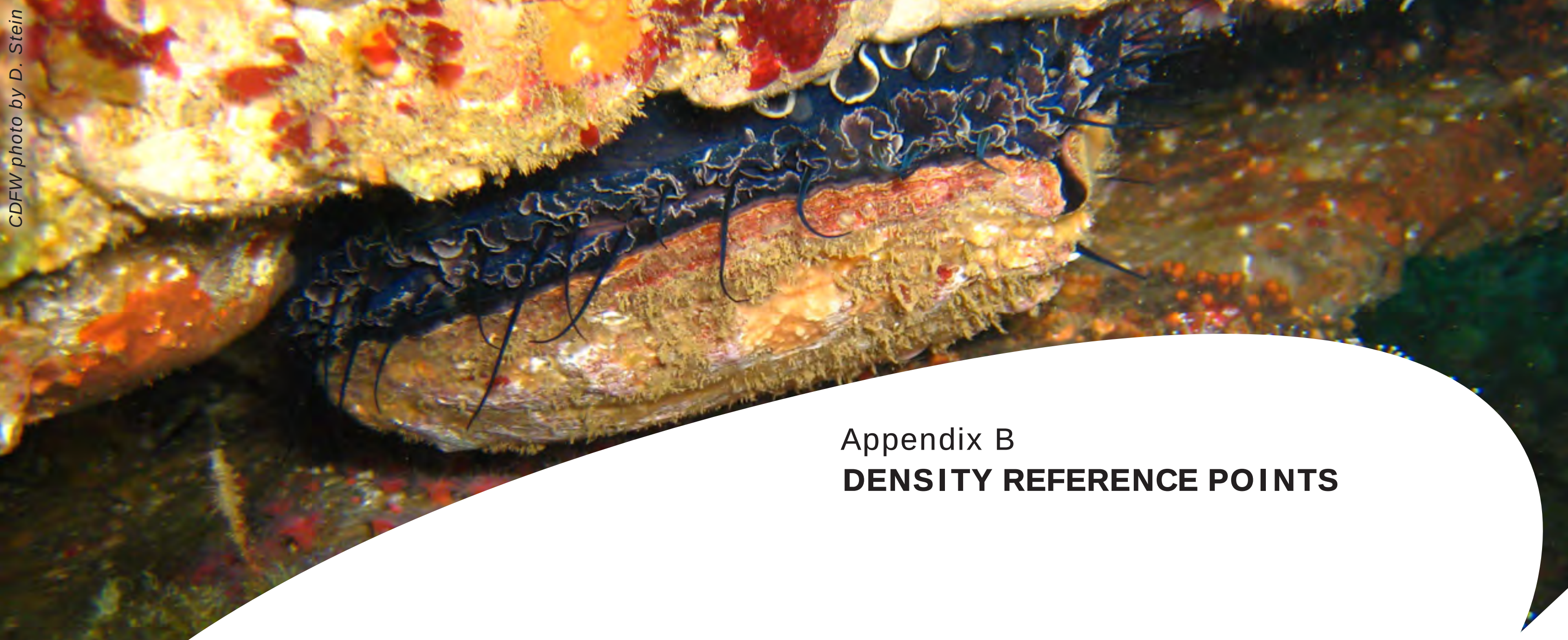
Appendix A, Table 1 Baseline estimate for red abalone densities averaged across eight index sites in the north coast fishery during the 2003-2007 survey period. Densities are averaged across four depth strata.

Site	Average	St. Dev.
Fort Ross	0.56	0.19
Timber Cove*	0.66	0.50
Ocean Cove	0.57	0.61
Salt Point**	0.67	0.74
Point Arena	0.59	0.41
Van Damme	1.01	0.78
Caspar Cove	0.48	0.50
Todd's Point	0.46	0.45
Average	0.63	0.17

* includes 2009 estimate for deepest depth stratum
**includes only transects within the sea urchin reserve

Reference

Karpov, K.A., P. Haaker, D. Albin, I.K. Taniguchi, and D. Kushner. 1998 The red abalone, *Haliotis rufescens*, in California: Importance of depth refuge to abalone management. J. Shell. Res. 17(3) 863-870.



CDFW photo by D. Stein

Appendix B
DENSITY REFERENCE POINTS

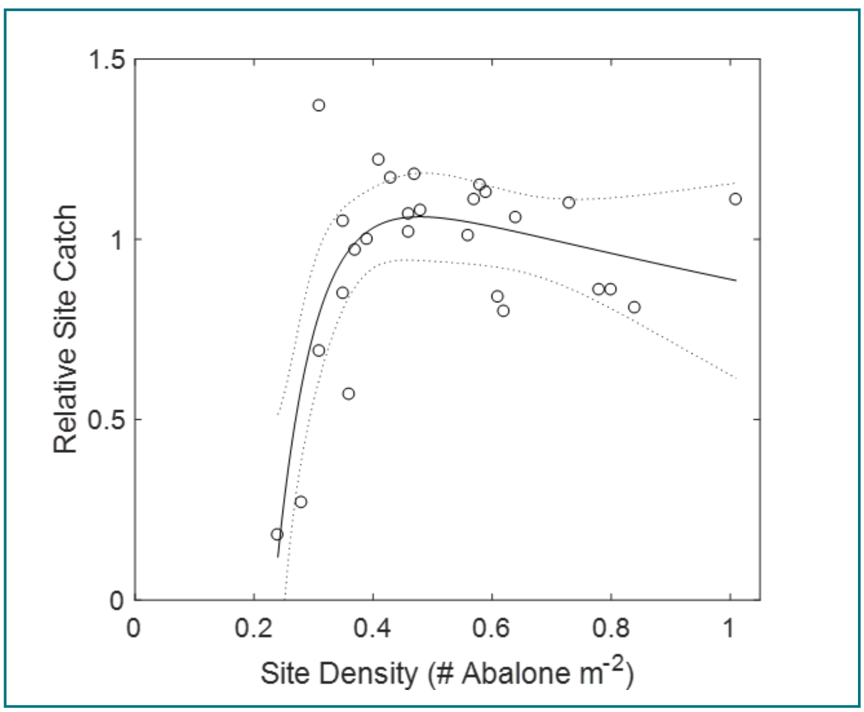
Target Density Reference Point

The FMP identifies a target density reference point to optimize productivity and catch. There are two density dependent features of abalone resource dynamics 1) low densities result in reduced reproductive output or Allee Effects and 2) low densities result in diminished fishery catches. The MLMA dictates that the goals of management is to maintain fisheries in a productive state based on population reproduction as well as optimal fishery performance.

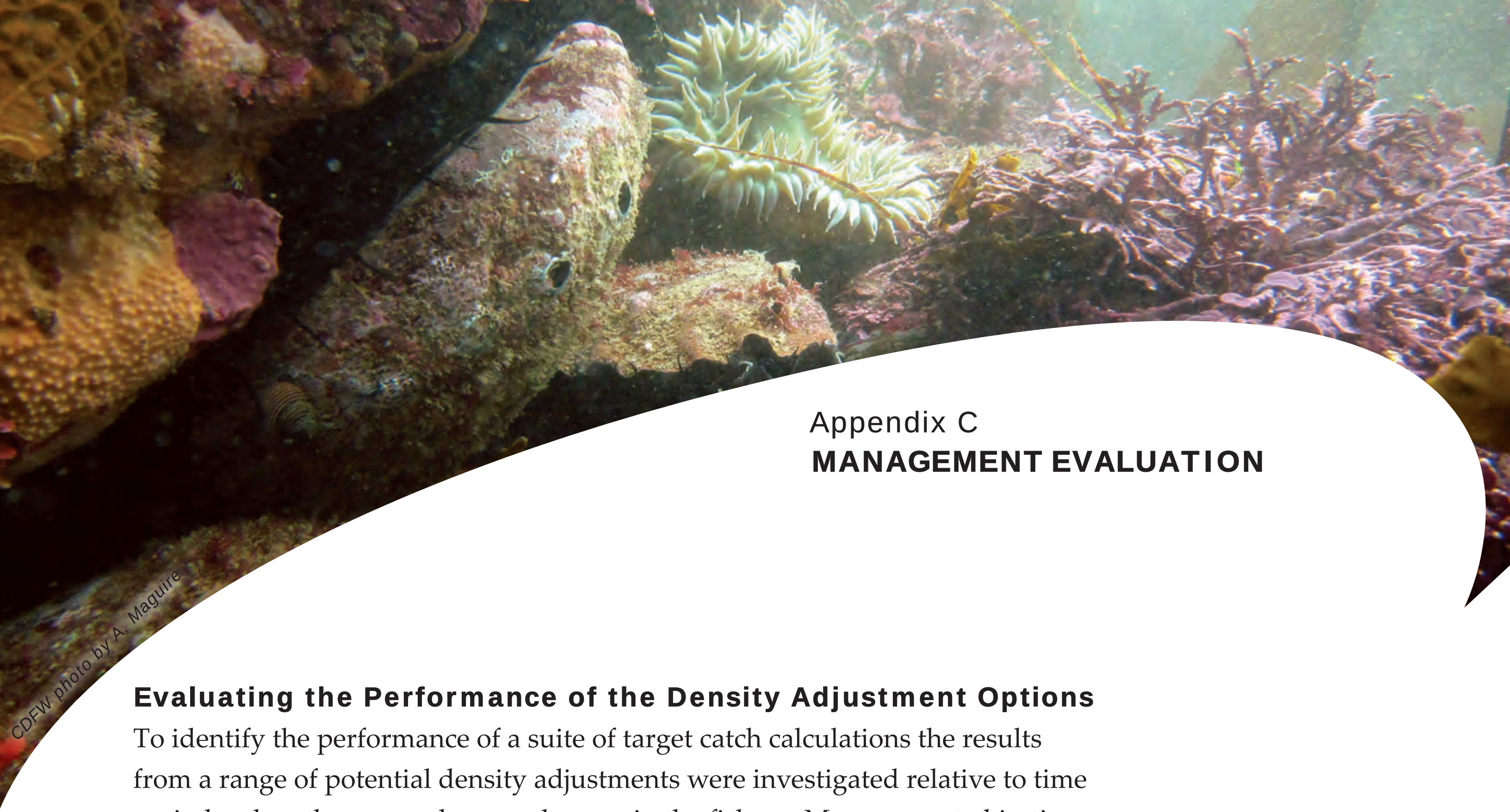
The relationship between density and catch at a site is assessed given the 16 year catch history for the fishery. To do this, historic catch levels at important fishery sites are examined across a range of densities. The catch at each of ten index sites was compared between 2003 to 2013 (after 2014 regulations changes confounded the comparison to earlier years). The site catch levels are assessed relative to that same site's baseline catch (2002-2006) comparing each site with itself rather than comparing between sites. The analysis shows how changes in density at each site impacted catch. Results show the range in densities was between 0.24 and 1.01 abalone/m^2 and that the range in relative catch levels was 0.18 to 1.37. All relative catch levels <0.8 corresponded to densities <0.37 abalone/m^2 showing low catches correspond to low densities. A two part exponential curve is fit to the combined standardized graph to look for the peak in catch. There was a cluster of relative catch points above 0.8 which is interpreted as a region with minimal density impact to fishery catch. Based on the model fit of the two part exponential curve ($R^2 = 0.5216$) a maximum relative catch at densities between 0.46 and 0.48 is observed (Appendix B, Figure 1). Rounding up to a density of 0.5 abalone/m^2 gives the target density reference point which produces robust catches while avoiding the steep declining region of the curve (on the left hand side of the curve in Appendix B, Figure 1).

Limit Density Reference Point

A key feature of the FMP is that a lower density limit is identified below which the fishery closes (catch is set to zero). Given the negative impacts of low densities to both diminished reproduction and catches the FMP prioritizes maintaining the fishery at high productivity densities above 0.3 abalone/m^2. This limit reference point of 0.3 abalone/m^2 is supported by decreased population recovery through reproduction failure observed in previous fisheries and is discussed in Chapter 3. This limit density point is also supported by reductions in catch demonstrated with this catch analysis. Relative catch drops to less than half its baseline level (relative catch = <0.5) when densities are below 0.3 abalone/m^2 (Appendix B, Figure 1). Therefore, the FMP sets the limit reference point to a density of 0.3 abalone/m^2 and if densities fall below the limit then the fishery will close and stocks will be allowed to rebuild without fishing pressure.



Appendix B, Figure 1. Two-term exponential fit of site density compared to relative catch at each site with the relative catch determined from the baseline catch at each site in the baseline years (2002-2006). The curve gives an X intercept (y=0) of x=0.233 abalone/m^2 and an R^2 = 0.5216. The maximum relative catch at 1.06 is between a density of 0.46 and 0.48 abalone/m^2.



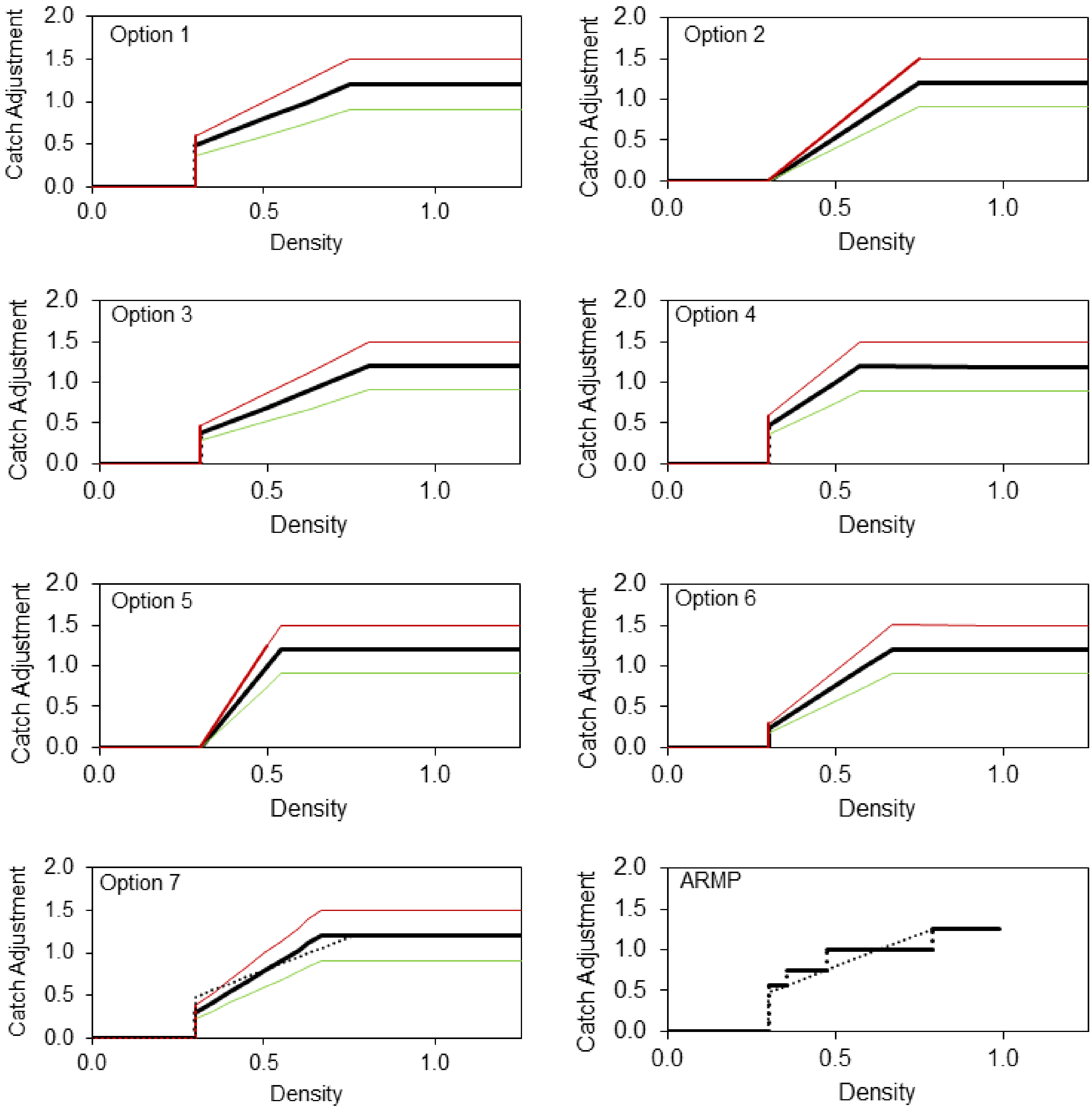
Appendix C
MANAGEMENT EVALUATION

Evaluating the Performance of the Density Adjustment Options

To identify the performance of a suite of target catch calculations the results from a range of potential density adjustments were investigated relative to time periods when there were known changes in the fishery. Management objectives were to respond in a timely fashion to important changes in the fishery. Two types of management responses are examined including fine and coarse tuning thresholds. Eight models of density adjustment are examined, including the ARMP, that are hindcast to evaluate their performance relative to fine and coarse tuning thresholds. Known years of impacts to the fishery are also examined relative to the performance of each density adjustment models.

Target Catch Adjustment Model Options

Target catch adjustment models are constructed representing different options for adjusting target catch based on average densities within a region. A total of seven density models are developed and compared with the ARMP model (Appendix C, Fig. 1). All of the density adjustments have a lower density threshold which closes the fishery at a density of 0.3 abalone/m^2 or lower. The models included an upper bound maximum density adjustment of the target catch of 1.2 along with a lower and upper maximum adjustment of 0.9 and 1.5, respectively. The models include upper and lower 25% bounds for the target catch. The models differed in the catch adjustments (0 to 0.6) at the threshold density with some being more or less conservative at that density. The first two models use baseline target catch levels of 0.63 abalone/m^2 (where the adjustment would be 1.0) and they differ at the lower threshold density of 0.3 abalone/m^2 with one having an abrupt cut off and the other gradually declining to zero catch (options 1 and 2). The next model is similar to Option 1 with the same slope but the overall catch adjustment is shifted down by 10% (y intercept 10% lower) to be more conservative (Option 3). The next set of models are similar but allow



Appendix C, Figure 1. Graphs showing target catch adjustment options 1-7 and the ARMP option depicting the relationship between density and the target catch adjustment. A target catch adjustment of 1.0 leads to no change in catch, while an adjustment <1.0 reduces the catch, and >1.0 increases the catch. All the target catch adjustment options have zero catch at a density of 0.3 abalone/m^2.

baseline target catches at 0.5 abalone/m^2 rather than baseline density of 0.63 abalone/m^2, making these options less conservative at higher densities (Options 4 and 5). The next option (Option 6) has the same slope as Option 4 with an intercept that is shifted lower by 25% making this option more conservative overall compared with Option 4.

The ARMP model (Model 8) was the density adjustment representing the harvest control rules within the ARMP using 25% changes in the density to trigger coarse management actions. This model option is used for comparison purposes with the other model options.

Performance Reference Points

The history of the fishery, during the period with catch data (2002-2016), had several years with known impacts to abalone in the two main fishery regions. In Sonoma County, there was increased fishing pressure in the years 2007-2009 (particularly at Fort Ross) which led to the drafting of a proposed decrease in fishing pressure (ISOR change in regulations) however the FGC did not implement the 25% reduction in the fishery at that time. Next, Sonoma County was the epicenter of a harmful algal bloom event toward the end of the fishing season in 2011 leading to a change in fishery management closing Fort Ross and decreasing fishing pressure implemented for the 2014 season. Most recently in Sonoma County, decreases in kelp and increases in sea urchins from 2015 to the present triggered reductions in the fishery first and then closure of the fishery in 2018. Following the Sonoma County HAB event there was a shift in fishing pressure to Mendocino Co. which led to higher catches in Mendocino in 2013. From 2015- present Mendocino County experienced decreases in kelp and increases in sea urchins negatively impacting red abalone resources leading to reductions in the fishery and then fishery closure in 2018. These important years within the fishery provided key time points for examining the hindcast model results to determine if the target catches generated would have initiated management responses in the reference years (Appendix C – Table 1 First Column).

Density Adjustment Model Results

The results of the management evaluation showed that a few of the density adjustment model options performed well during the hindcast triggering management actions during the majority of years identified as important performance reference points (Appendix C, Tables 1 and 2). In Sonoma County, the density adjustment options 1, 5 and 6 performed well in the hindcast evaluation (Appendix C, Table 1). In Mendocino County, the density adjustment options 4 and 5 also performed well in the hindcast evaluation (Appendix C,

Appendix C, Table 1. Sonoma County. Management performance of a suite of catch adjustment models for Sonoma County comparing performance reference years where management actions were recommended with the results from the hindcast for each of 7 catch adjustment options. Check marks indicate a match of the model performance with the reference year and Action indicates a mismatch with a management action recommended by the model when it is NOT indicated during the reference year. Options 1, 5, 6 and 7 performed best.

Year	Performance Reference	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
2002	-	✓	Action	Action	✓	✓	✓	✓
2003	-	✓	Action	Action	✓	✓	✓	✓
2004	-	✓	Action	Action	✓	✓	✓	✓
2005	-	✓	✓	✓	✓	✓	✓	✓
2006	-	✓	Action	✓	✓	✓	✓	✓
2007	-	✓	✓	Action	✓	✓	✓	✓
2008	-	✓	Action	Action	✓	✓	✓	✓
2009	Action	✓	✓	✓	✓	✓	✓	✓
2010	Action	✓	✓	✓	0	✓	✓	✓
2011	-	✓	Action	✓	Action	✓	✓	✓
2012	Action	✓	✓	✓	✓	✓	✓	✓
2013	-	✓	Action	Action	✓	Action	Action	Action
2014	-	Action	Action	Action	Action	Action	Action	Action
2015	Action	0	✓	✓	0	✓	✓	✓
2016	Action	✓	✓	✓	✓	✓	✓	✓

Table 2). Using these results Option 7 is created as a combination of the best features of options 1, 5 and 6 plus the addition a steeper slope resulting in more catch at higher densities and less catch when densities are low.

Target catch adjustment Option 7 used in the FMP is characterized by a suite of features. The first feature is an abrupt cut off at the lower density of 0.3

Appendix C, Table 2. Mendocino County. Management performance of a suite of catch adjustment models for Mendocino County comparing performance reference years where management actions were recommended with the results from the hindcast for each of 7 catch adjustment options. Check marks indicate a match of the model performance with the reference year and Action indicates a mismatch with a management action recommended by the model when it is NOT indicated during the reference year. Options 4, 5 and 7 performed best.

Year	Performance Reference	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
2002	-	✓	Action	Action	✓	✓	✓	✓
2003	-	Action	Action	Action	✓	✓	✓	✓
2004	-	✓	✓	✓	✓	✓	✓	✓
2005	-	Action	Action	Action	Action	Action	✓	✓
2006	-	✓	✓	✓	✓	✓	✓	✓
2007	-	Action	Action	Action	✓	✓	Action	Action
2008	-	✓	Action	Action	✓	✓	✓	✓
2009	-	Action	Action	Action	✓	✓	Action	Action
2010	-	✓	Action	✓	✓	✓	Action	✓
2011	-	✓	Action	✓	✓	✓	✓	✓
2012	-	✓	Action	Action	✓	✓	✓	✓
2013	Action	✓	✓	✓	0	0	✓	✓
2014	-	✓	Action	✓	✓	✓	✓	✓
2015	Action	0	✓	✓	0	0	0	0
2016	Action	✓	✓	✓	✓	✓	✓	✓

abalone/m^2 rather than a gradual decline to zero catch with a steep slope in the density adjustment sliding scale line reducing catch. In this model, the catch adjustment at 0.5 abalone/m^2 is proportional to the baseline density (0.5/0.63 = 0.79 catch adjustment). This results in a density of 0.59 abalone/m^2 being treated as the point where the catch is not adjusted (multiplied by 1.0) making catch less conservative at higher densities (same as Option 6). The density at which the catch adjustment is maximized is at 0.67 (the same as Option 6). Meanwhile, the threshold catch adjustment is more conservative between densities of 0.3 and 0.5 (relative to Option 1), with the lower density catch adjustment at 0.48 (the same as Option 1). Option 7 has more conservative catches at the lower densities and less conservative catches at densities higher than 0.5 relative to Option 1 (as depicted with the dotted line in the graph of Appendix C, Figure 1, Option 7). Option 7 performed as well or better than the other density adjustments options in the management evaluation (Appendix C, tables 1 and 2) and is selected as the density adjustment sliding scale model for inclusion in the FMP.