Journal of Shellfish Research, Vol. 26, No. 3, 713–717, 2007.

APPLICATION OF RECENT RED ABALONE *HALIOTIS RUFESCENS* SURVEYS TO MANAGEMENT DECISIONS OUTLINED IN THE CALIFORNIA ABALONE RECOVERY AND MANAGEMENT PLAN

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ABSTRACT The management section of California's recently adopted Abalone Recovery and Management Plan (ARMP) uses results of fishery independent transect surveys at eight index sites to regulate total allowable catch (TAC) for the recreational red abalone, *Haliotis rufescens* (Swainson), fishery. The ARMP uses abalone densities over all depths, densities in deep water (8.4–19.7 m), and successful recruitment (>4,500 abalone/hectare in the 100–177 mm size class) to decide whether changes need to be made in the TAC (see Table 1 later). The catch is estimated from telephone surveys and returned abalone permit report cards. Recent surveys in 2003 and 2005 at four of the eight index sites show red abalone densities in the range of the baseline densities established by surveys in 1999 and 2000. Applying the results of the 2003 and 2005 surveys to the ARMP criteria indicates no change is needed in the current TAC. Two-way ANOVA showed there were no significant differences in density between sites (Van Damme and Salt Point; df = 1, F = 0.06, $P > 0.8$) and time periods (df = 1, F = 1.33, $P > 0.25$) for all depths combined. Likewise there were no significant differences at deep depths between the two sites (df = 1, F = 0.23, $P > 0.63$) and the two time periods (df = 1, F = 0.10, $P > 0.75$).

KEY WORDS: *Haliotis rufescens*, red abalone, management, transect surveys

INTRODUCTION

The northern California recreational red abalone fishery has remained productive for over 60 y, whereas recreational and commercial abalone fisheries throughout the remainder of the state have collapsed and are now closed (Karpov et al. 1998, Karpov et al. 2000). The success of this apparently sustainable fishery is believed to be the result of management policies, which prohibited the use of scuba and surface-supplied air and commercial fishing (Karpov et al. 1998). Because this is a recreational only fishery, it has less of the economic pressures that can increase the difficulty of regulating commercial fisheries (Shepherd & Rodda 2001). A distinct disadvantage of a recreational only fishery is difficulty in obtaining total catch data but this problem has recently been addressed (Kalvass & Geibel 2006).

The Abalone Recovery and Management Plan (ARMP, <http://www.dfg.ca.gov/mrd/armp/index.html>) was adopted by the California Fish and Game Commission on December 9, 2005. The ARMP sets guidelines for both managing the one remaining fishery on northern California red abalone and fostering the recovery of five species of abalone populations in the rest of the state. The ARMP continues the successful northern California recreational abalone fishery management policies of the past and adds increased fishery independent surveys to monitor the status of abalone populations. A key tool in the ARMP for both management and recovery is fishery independent dive survey data collected at index sites.

The ARMP utilizes densities determined from transect surveys to manage red abalone populations in northern California. If densities drop below critical values, the ARMP either reduces the catch, closes areas, or the entire fishery. Conversely, if densities rise and there is evidence of good recruitment, the total allowable catch (TAC) could be increased. The fishery closure density in the ARMP is 3,000 abalone/hectare and is set at a precautionary level that should protect the reproductive capability of red abalone populations. The TAC is a guideline rather than a trigger, because there are no mechanisms for monitoring in-season catch and for closing the fishery in-season when the TAC is exceeded. The main management strategy is to maintain abalone densities above a minimum viable population (MVP) level below which recruitment would likely be diminished and the fishery would collapse (Shepherd & Brown 1993, ARMP). This study reports the results of recent transect surveys as they relate to management decisions based on the ARMP.

METHODS

The ARMP uses density levels (Table 1, ARMP Table 7–2) to regulate the TAC for the fishery based on results from dive surveys at eight index sites (Fig. 1). The catch and effort are estimated from telephone surveys and returned abalone permit report cards (Kalvass & Geibel 2006). The main criteria are densities of red abalone at all depths and at deep depths, with recruitment densities a consideration in some instances. The ARMP estimated a sustainable fishery density for all depths of 6,600 abalone per hectare by averaging densities at three heavily used index sites (Van Damme, Salt Point, and Fort Ross State Marine Conservation Areas) surveyed in 1999 and 2000 (Table 2). This average density is the best estimate of an abalone density, which can support an ongoing fishery. An average density of 3,300 abalone per hectare was also calculated for deep-water populations (from 8.4–19.7 m). Deep abalone are believed to be refuge populations because regulations prohibit the use of scuba and surface-supplied air, which greatly limits the ability of most divers in reaching abalone at deep depths (Karpov et al. 1998). The use of deep abalone as a criterion reflects the

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TABLE 1.

TAC adjustment table from Abalone Recovery and Management Plan.

Criteria					
		Density (ab/ha) (emergent surveys)			
Recruitment		Deep (refuge)		All Depths	Action
Yes (>4,500 in 100–177 mm size range)	AND	>4,100	AND	>8,300	1) Increase TAC by 25% (to max 500,000 ab/yr or 125% of revised TAC)
N/A		3,300	AND	6,600	2) Maintain TAC (400,000 ab/yr or revised TAC)
No	AND	<2,500	OR	<5,000	3) Reduce TAC by 25% increments
N/A		N/A		<3,000	4) Close Fishery
N/A		>3,300	AND	>6,600	5) Reopen Closed Fishery

importance ascribed to potential refuge populations in the ARMP.

In 2003 the California Department of Fish and Game (CDFG) contracted the dive program at California State University, Humboldt to conduct dive surveys at Van Damme State Marine Conservation Area and Arena Cove to assess abalone and sea urchin populations in northern California. The CDFG revised the protocol for transect surveys beginning in 2003 to clarify procedures but the data collected are comparable to past transect surveys. Two divers survey a 1-m wide swath on opposite sides of a 30 m transect tape. Emergent transect sampling was conducted in which all juvenile and adult abalone that can be seen without moving substrate or using a flashlight to search crevices are counted and measured. Transects were relocated if more than 50% of the substrate was soft. In 2005 the CDFG conducted dive surveys at Caspar Cove and Salt Point State Marine Conservation Area. Each index site had a target of 36 transects at random locations evenly divided between shallow and deep stations.

Figure 1. Index sites used to monitor the northern California recreational red abalone fishery in the ARMP.

Power analyses using data from previous surveys indicated 36 transects would have an 80% chance of detecting a significant difference between samples. For example, using data from the 1999 Fort Ross survey, a mean of 0.43 abalone/m^2 and standard deviation of 0.53 abalone/m^2 can detect a 100% effect at $n = 25$ transects. Although the detectable effect size seems to be large, much of the variation in transect density is likely to result from abundance variability of relatively rare abalone on either side of the size range (Gorfine et al. 2001), which would make average densities from transects more robust than statistics would indicate.

Transect locations at Arena Cove and Caspar Cove were selected from random points generated by an ArcView GIS 3.2 extension (Jenness Enterprises, Flagstaff, AZ) in depth ranges of 1.5–4.6 m, 4.9–7.6 m, 9.1–13.7 m, and 14.0–19.7 m as shown on United States Geological Survey (USGS) topographic map depth contours. Transect locations often needed to be relocated inshore because mapped contour lines were inaccurate and tended to be deeper than shown. Transect locations at Salt Point duplicated stations used in 1986 (Parker et al. 1988). Van Damme transects duplicated stations used in 1989 through 1992 that had been selected using a systematic random approach (Karpov et al. 1998). Future surveys will likely be based on randomly generated points rather than duplicating previously used stations. Whereas random points will likely increase variation between years, they would provide better representation of the survey site than repeated surveys of the same stations.

A two-way ANOVA was used to compare red abalone density between sites and time periods for all depths at two of the sites (Van Damme and Salt Point), which were surveyed in the two time periods. Abalone densities at deep depths were also analyzed using ANOVA.

RESULTS

Data from the 2003 and 2005 surveys show relatively high densities of abalone (Table 3). These four sites represent half of the data required by the ARMP for evaluating the fishery using the TAC adjustment table (Table 1). The other half of the data, not yet collected, will come from surveys at Fort Ross State Marine Conservation Area and three new index sites at Todds Point, Timber Cove, and Ocean Cove (Fig. 1).

Average densities for the 2003 and 2005 sites are higher than those in 1999 and 2000 and approach the deep and the

TABLE 2.

Survey results from 1999 and 2000 used to calculate sustainable red abalone fishery density in the ARMP.

Site	Number of Deep Transects	Deep Density (Abalone/ha)	Number of Combined Transects	Combined Density (Abalone/ha)
Van Damme	13	1,400	34	7,600
Salt Point	13	5,200	22	8,300
Fort Ross	16	3,200	31	4,300
Totals/Averages	42	3,300	87	6,600

TABLE 3.

Survey results from 2003 and 2005 with critical values for TAC changes from the ARMP.

Site/Year	Deep Transects	Density (Abalone/ha)	All Depths Transects	Density	Recruitment Density (100–177 mm)
Van Damme 2003	17	5,100	33	10,700	4,000
Arena Cove 2003	20	3,700	38	5,700	1,800
Salt Point 2005	16	2,800	36	8,900	2,700
Caspar Cove 2005	12	4,600	29	7,500	3,900
Average		4,000		7,900	3,100
Critical Values for:					
25% TAC increase		4,100		8,300	4,500
25% TAC decrease		2,500		5,000	Not Applicable

all-depths density criteria for increasing the TAC (Table 3). Recruitment densities are far short of the criterion for TAC increase (Table 3) and would prevent an increase in the TAC.

Plots of density and size frequency show generally a low density of abalone in the 100–150 mm size groups at the 2003 and 2005 surveyed sites with much of the population above the legal size (Fig. 2). Van Damme is a possible exception; however, densities of sublegal sized abalone were not as high as the standard set in the ARMP (Table 3). Except for Caspar Cove, there are also relatively few abalone in deep stations compared with all depths (Fig. 2, Table 3).

Van Damme is the site most frequently surveyed since 1986. A time series of size frequency at Van Damme shows the relative lack of sublegal sized abalone in more recent surveys (Fig. 3).

A two-way ANOVA was used to compare red abalone density between sites and time periods for all depths at two of the sites (Van Damme and Salt Point), which were surveyed in the two time periods. Abalone densities at deep depths were also analyzed

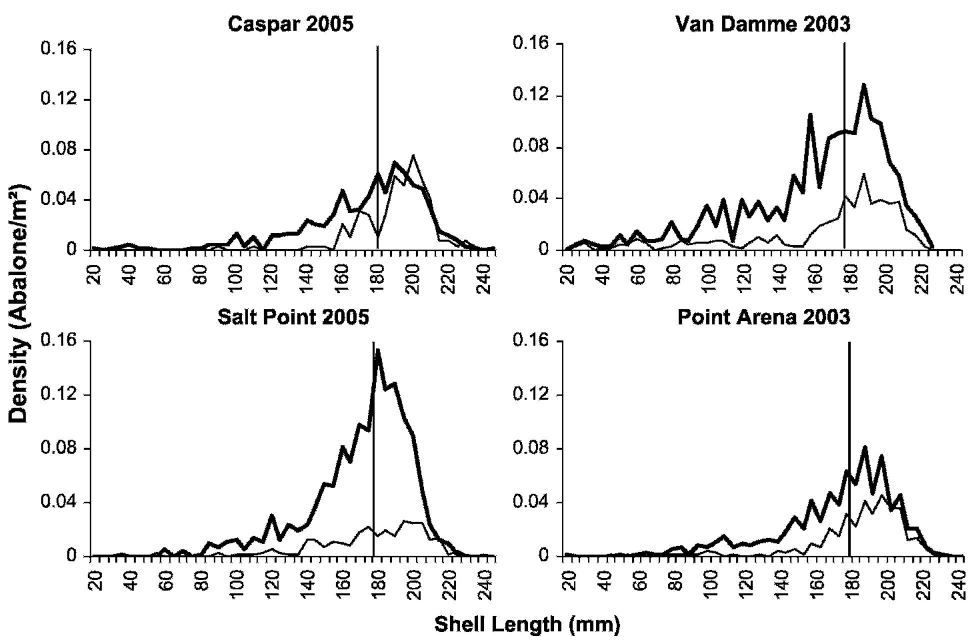

Figure 2. Red abalone densities in relation to length for recently surveyed ARMP index sites (Size distributions of shallow stations are represented by bold lines; size distributions of deep stations are represented by fine lines; vertical lines mark legal size for red abalone.).

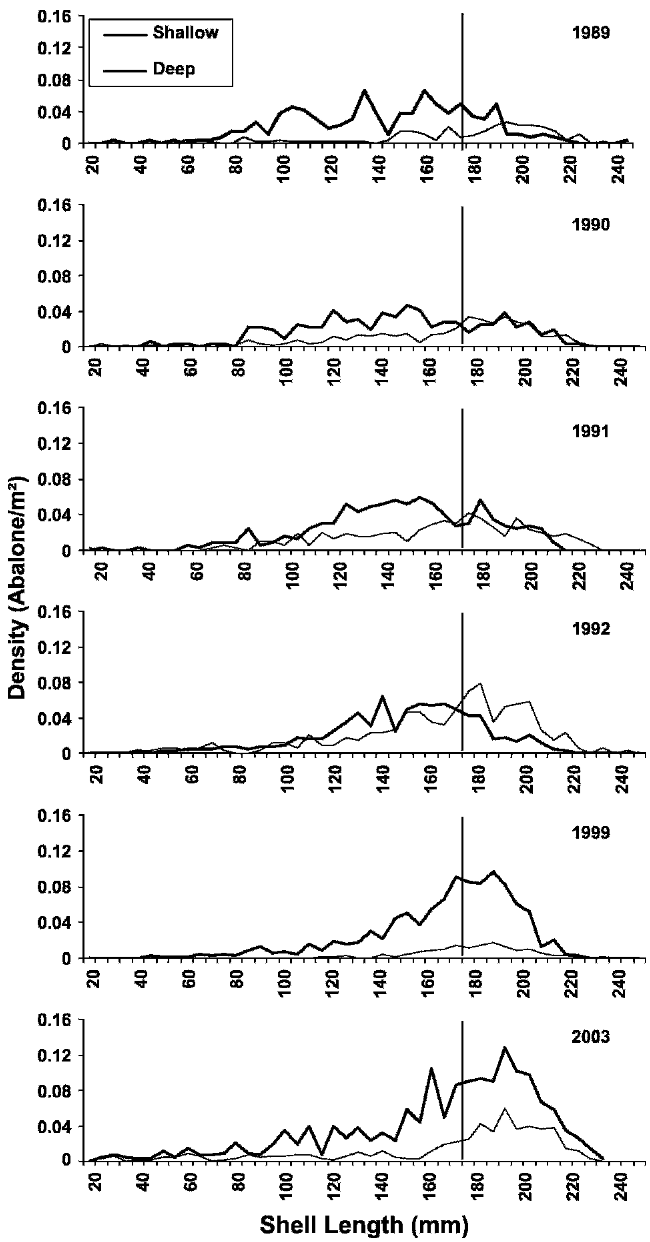

Figure 3. Red abalone densities in relation to length for Van Damme time series. (Size distributions of shallow stations are represented by bold lines; size distributions of deep stations are represented by fine lines; vertical lines mark legal size for red abalone.)

using ANOVA. Two-way ANOVA showed there were no significant differences in density between sites (Van Damme and Salt Point; df = 1, F = 0.06, $P > 0.8$) and time periods (df = 1, F = 1.33, $P > 0.25$) for all depths combined. Likewise there were no significant differences at deep depths between these two sites (df = 1, F = 0.23, $P > 0.63$) and time periods (df = 1, F = 0.10, $P > 0.75$).

DISCUSSION

Red abalone densities in four recent surveys show abalone densities at levels, which would maintain the current TAC according to the ARMP TAC adjustment table (Table 1). Surveys at four other index sites are required before a final decision would be made regarding whether changes should be made in the TAC.

The recruitment criterion was not met by the survey results. Recruitment is a secondary criterion in the ARMP and is only considered when the TAC might be increased (Table 1). The recruitment criterion is based on levels seen during the relatively high recruitment at Van Damme in 1992. This criterion is a precautionary measure that ensures a large number of sublegal sized abalone are available before an increase is made in the TAC. Although surveys since 1992 have been limited, there is no evidence of high recruitment levels in subsequent years.

Density and length graphs for the recent surveys show relatively low numbers of small abalone and a high proportion of legal sized abalone at each site (Fig. 2). This supports the idea that low reproductive rates are common to multiple locations and not an aberration of one or two sites. The general lack of small abalone indicates high levels of reproduction are infrequent in red abalone (Tegner et al. 1989, Karpov et al. 2001).

The time series of size frequency graphs at Van Damme provides valuable information on reproduction and growth for the site by showing changes in population structure over time (Fig. 3). The current fishery is probably dependent on one or more large cohorts, which appeared in the 1989 survey as 100–140 mm abalone. By 1999 many of the small abalone from 1989 had grown close to legal size and appear to have increased the overall densities of legal sized abalone.

The general lack of small abalone indicates high levels of reproduction are infrequent in red abalone (Tegner et al. 1989, Karpov et al. 2001). The time series at Van Damme shows one or more large cohorts of small abalone (100–140 mm) in 1989. In subsequent years, the abalone appear to be growing but are not replaced by similar numbers of small abalone (Fig. 3). The presence of small abalone in the 1989 survey shows the sampling methodology is adequate for sampling small emergent abalone but apparently during most years such abalone are absent. Low abundance of small abalone in 1999 indicates recruitment levels in previous years were low in comparison with 1989–1992.

Low numbers of small abalone could lead to stock depletion if catch rates exceed the number of young abalone growing to the legal size limit. Most of the sublegal abalone in 2003 and 2005 were close to the legal size and should reach legal size within a few years leaving relatively fewer small abalone for future years. Abalone densities will need to be carefully monitored to ensure that abalone populations do not fall significantly from fishing activities. The ARMP monitoring schedule of triennial scuba surveys for eight sites should adequately detect red abalone population declines before adverse fishery conditions occur.

An estimate of average abalone recruitment is needed to determine whether the fishery can be sustained without large recruitment events similar to those detected in 1989. To obtain abalone recruitment estimates, habitat mapping would be needed along with randomized transect surveys. These data would be used to calculate the number of young abalone in an area to determine whether the fishery is sustainable without another large recruitment event. There were more small abalone seen in the 2003 Van Damme survey than in 1999; however, further studies are needed to determine if those abalone survive and contribute to the population.

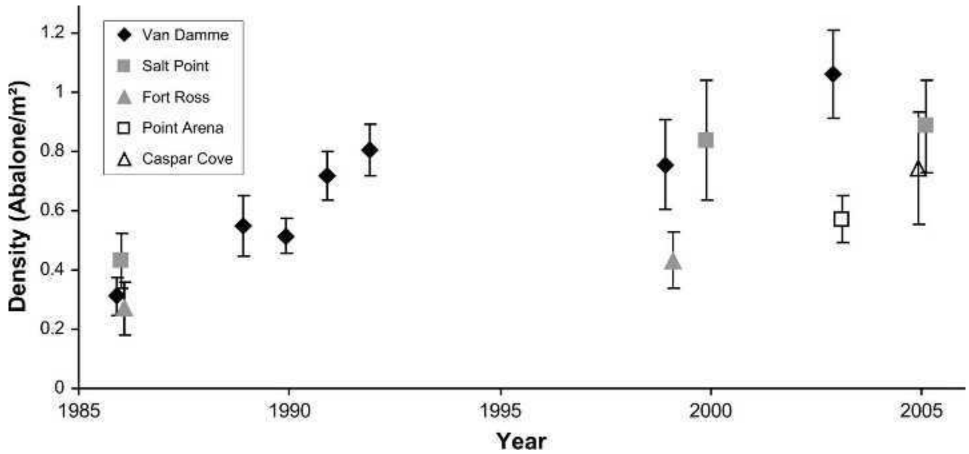

Figure 4. Red abalone densities at all depths for transect surveys at Van Damme, Salt Point, Fort Ross, Point Arena, and Caspar Cove (vertical lines represent standard error).

Because each index site has a target of 36 transects, a total of 288 transects are needed for each three-year monitoring cycle. This number of transects might be better used as randomly placed transects that would be more representative of the whole red abalone fishery than transects restricted to index sites. The random transects would include areas away from the index sites and could be used to make a more reliable estimate of population size with habitat maps. A more randomized sampling scheme would also be a first step towards implementing the Long-term management plan in the ARMP. The Long-term plan would establish management zones that would allow more flexibility in managing the fishery and might use tags to increase control over the legal take of abalone within the zones. Randomized sampling would provide data helpful in determining zone boundaries.

Red abalone abundance seems to be increasing over time or at least has remained stable (Fig. 4). The increases in red abalone densities, might be explained by postulating the large recruitment event seen in the 1989–1992 surveys at Van Damme, had counterparts throughout northern California. The management of red abalone in northern California should be cautious because the health of the fishery could be largely based on recruitment events first observed in 1989, which have not been duplicated since. The ARMP provides a cautious framework for managing the fishery with the data available.

ACKNOWLEDGMENTS

The authors thank the many divers and biologists who participated in survey data collection over the years. Their special thanks to Konstantin Karpov who initiated the Van Damme time series, offered suggestions for improving the manuscript and provided assistance with statistical analyses. They are also grateful for the statistical advice of John Geibel, the field assistance of Andrew Lauermann who coordinated the 2003 surveys, participants of the 2005 survey including the skippers and crew of CDFG Patrol Vessel *Marlin* for support logistics, John Ugoretz and Tony Warrington for supporting and organizing the use of the vessel on short notice, Dr. Laura Rogers-Bennett for coordinating the Sonoma County portion of the survey, the help of Peter Kalvass, and two anonymous reviewers in critiquing the manuscript.

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