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Chapter 26
The California red abalone fishery: a case study in complexity

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ABSTRACT: The red abalone, *Haliotis rufescens* (Swainson), is historically the most important species in the California abalone fishery by virtue of its large size and distribution along the entire coast. Red abalone range through three regions varying considerably in food availability, predators and predation pressure and the physical characteristics of their habitat; these factors affect population structure, growth, reproduction and behaviour. The commercial fishery is largely restricted to southern California, sea otter (*Enhydra lutris*) predation has precluded most fishing in central California, and the north coast has been reserved for recreational fishermen since 1945. Thus both biogeography and politics complicate management of this haliotid. Management of commercial and recreational fisheries has been based primarily on size limits plus a daily bag limit for sport fishermen. In spite of continued market demand, commercial landings declined precipitously in the early 1970s after many years of relative stability. Limited entry was instituted in 1977, but the downward trend has continued unabated, and now recreational take on the north coast is apparently larger than the commercial harvest. These factors plus rapidly rising prices for abalone have put additional pressure on stocks of the north coast, and the advent of a sea-urchin fishery in this region has apparently led to a major poaching problem. While culture is technically feasible, stock enhancement measures have yet to be proven effective. Thus for the near term, the future of the red abalone fishery will depend upon better management of existing stocks.

RESUMEN: El abulón rojo, *Haliotis rufescens* (Swainson), es históricamente la especie más importante en la pesquería comercial, debido a su gran tamaño y a que se distribuye a todo lo largo de la costa del Estado de California. Los abulones rojos se distribuyen en tres regiones, las cuales varián considerablemente en disponibilidad de alimento, depredadores, presíon de depredación y en las caracteristicas físicas de su habitat. Estos factores afectan la estructura de la población, el crecimiento, la reproducción y su conducta. La pesquería comercial está en gran medida restringida al Sur de California; la depredación ejercida por la nutria marina (*Enhyra lutris*) ha evitado que se pesque más en el Centro de California y la Costa Norte ha sido reservada a la pesca deportiva desde 1945; así, la biogeografiá y la política complican la administración de este haliotido. La administración de la pesquería comercial y deportiva se ha basado en tamaño mínimo y además, para los pescadores deportivos, en un número limitado. A pesar de una contínua demanda en el mercado, las descargas comerciales disminuyeron precipitadamente al inicio de la decada de los 70s, después de muchos años de relativa estabilidad. En 1977 se restringió la incorporación de nuevos pescadores, pero la tendencia a la baja se ha mantenido, y en la actualidad, la captura deportiva de la Costa Norte aparentemente es mayor que la captura comercial. Estos factores, además de una elevación rápida de los precios del abulón, han sumado presiones adicionales a los stocks de la Costa Norte; asímismo, el desarrollo de la pesquería de erizos en esta zona, aparentemente ha contribudo a un agravamiento del problema de pesca furtiva. En tanto que el cultivo es técnicamente factible, las medidas de mejoramiento de poblaciones aún tienen que probar su efectividad; por lo que a corto plazo, el futuro de la pesquería del abulón rojo dependerá de una mejor administración de las poblaciones existentes.

INTRODUCTION

The red abalone, *Haliotis rufescens* (Swainson), is historically the most important species in the California abalone fishery by virtue of its size and distribution throughout the state. Reported to 298.6 mm (R. Warner, pers. comm.), it is the largest member of the genus (Cox, 1962). With a geographical range extending over 16° of latitude, from Coos Bay, Oregon, to Bahia Tortugas, Baja California (Cox, 1962), this species inhabits a range of ecosystems varying widely in physical and biological makeup. These factors affect population dynamics and fishery management. An evaluation of sport and commercial fisheries for red abalone in light of recent research is long overdue; the last major treatment was published by Cox in 1962. Since that time a variety of factors affecting the fishery have changed, including the expansion of predator populations, increased fishing power and growth of sport utilization. These factors, coupled with continued commercial demand, apparently led to the major decline in commercial landings in recent years. The diminishing supply and continued pressure on the resource have also been blamed for an increase in illegal commercial harvest in areas of Northern California reserved for the recreational fishery since 1945.

Here we review the biology of red abalone, how it changes regionally within California and its effects on fishery management. We focus on northern California, where most animals are now taken, and the object of recent research. An historical review is provided of commercial landings with an emphasis on changes since the Cox (1962) report. We contrast commercial fishing trends in south-central California to the San Francisco area, evaluating recent changes in landings and market value. The effort and landing estimates from the 1985–8 sport fishing assessment in northern California are presented to allow comparison with levels of commercial harvest in the rest of the state. We conclude with a discussion of the continuing challenges facing managers of the red abalone fishery.

RED ABALONE BY REGION

Biogeographic differences and present management regulations effectively divide the state into three regions (Fig. 26.1). A major predator, the sea otter (*Enhydra lutris*), precludes abalone fishing within its current established range in Central California (US Fish and Wildlife Service, 1987). The commercial fishery is restricted to southern California, including the Channel Islands, and in the portion of northern California from San Mateo County to Point Lobos in San Francisco County and the Farallon Islands, immediately north of the present sea otter range. The north coast, from Marin County to the Oregon border, is reserved for sport fishing. Latitudinal gradients in temperature, light and oceanographic conditions further affect the distribution of red abalone and their habitat in patterns which roughly follow this same division into three regions.

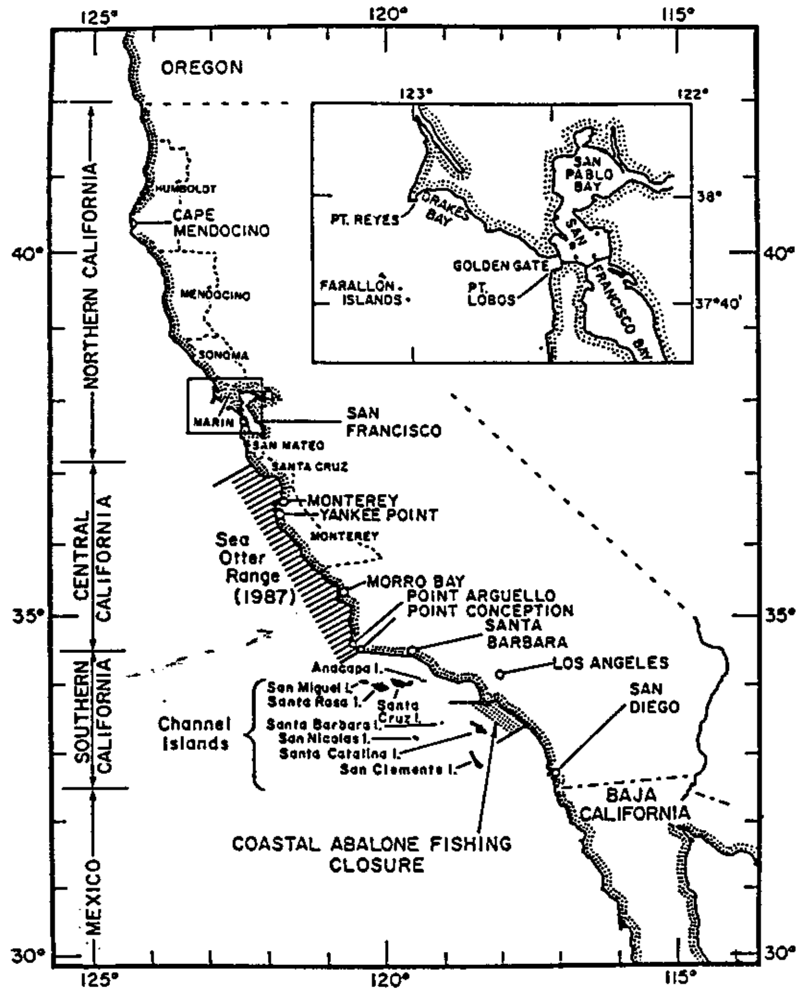

Fig. 26.1 Map of California with place names mentioned in the text.

Physical habitat, depth distribution and food supply

Red abalone are sparse north of Shelter Cove, Humboldt County (Fig. 26.1). The coastline in this region is subject to very severe ocean conditions, major rivers contribute much freshwater and sediment, and the temperature range is well below the optimum for this species (Leighton, 1974). Red abalone occur from the lower intertidal to no deeper than 6–7 m, the lower depths of their food supply in this area. The abundance of food species is highly seasonal, and standing crops are low relative to sites further south. While reduced salinities or sand abrasion may be harmful to abalone, the low abundances of other grazers suggest limitation by food supply.

The major sport fishery of northern California occurs in Mendocino and Sonoma

Counties (Fig. 26.1). This coastline is also highly exposed, but the waters are less turbid and the photic zone is deeper. Red abalone are most abundant from the lower intertidal to about 7–8 m, but are found in depths to 25 m where appropriate drift algae are supplied by surge channels (Deacon, 1977; Parker *et al.*, 1988; J.D. DeMartini pers. obs.). These observations and the migration patterns between deep and shallow water in response to highly seasonal and depth-limited abundance of algae reported by Ault and DeMartini (1987) indicate that the availability of algal drift sets the lower depth limit.

One of the authors (J.D. DeMartini, unpublished data) has studied feeding behaviour on the north coast, focusing on a site in Mendocino County. Red abalone food consisted primarily of annual brown algae (*Alaria marginata* and *Costaria costata* accounted for 58% of the feeding observations, N = 552) and virtually all observations involved drift. Food species generally started appearing by mid-spring, although the intensity of initial growth was extremely variable. These algal species started dying back by late summer and by mid-autumn virtually no food was available, a condition which persisted to the following spring. During the season of algal availability, the presence of drift and feeding behaviour both correlated with rough seas. The seasonality of food production and its temporal and spatial variability within this season favour opportunistic feeding, and abalone were observed consuming 18 species of macroalgae.

Marin through Santa Cruz Counties (Fig. 26.1) are all characterized by turbid waters; Marin and San Francisco Counties are strongly impacted by the outflow from San Francisco Bay. Major ecological changes begin in Santa Cruz County. A perennial and copious drift producer, *Macrocystis pyrifera*, becomes the dominant kelp; while there is an annual cycle of abundance, drift kelp is available virtually all year (Gerard, 1976). From Monterey County south, the photic zone deepens and algal productivity is very high. Red abalone are distributed from the lower intertidal to the outer edge of kelp forests.

Ambient temperatures strongly affect abalone distributions in southern California, where changes in current patterns create warmer environments. Red abalone are most abundant along the northwestern Channel Islands and along mainland sites where upwelling produces cooler temperatures, notably the areas north and west of Santa Barbara, the Palos Verdes Peninsula and San Diego. The distribution of red abalone becomes deeper with increasing ambient temperatures and deeper kelp forests to the south; off San Diego their minimum depth is about 12 m and their range extends to the outer edge of the kelp forest, about 25 m. *Macrocystis* is both the major source of drift in Southern California (Tegner & Dayton, 1991) and the preferred food of this haliotid (Leighton, 1966).

Competitors, predators and mortality rates

Two echinoids, the red (*Strongylocentrotus franciscanus*) and the purple (*S. purpuratus*) sea urchins, are other abundant, conspicuous invertebrates specializing on drift, and these species also range throughout the state. The apparent sea-urchin population explosion in southern California in the 1960s may have partially resulted from reduced competition with abalone (North & Pearse, 1970). While the negative impact of red abalone on the growth rate of red urchins is apparently not strong (Tegner & Levin, 1982), sea urchins clearly have a detrimental effect on other herbivores when food is limiting. These echinoids attack attached plants when drift becomes scarce; *en masse* they are capable of destroying entire stands of kelp, eliminating drift production and preventing regeneration of the vegetation. A red-urchin fishery, which began in the early 1970s and has now spread throughout California, has reduced the incidence of destructive grazing episodes by this species, but purple uchins remain a problem in some areas (reviewed by Tegner, 1989). Prior to the 1980s, red urchins dominated rocky bottoms below 6–7 m in Mendocino and Sonoma Counties apparently limiting algae to shallower depths. With the advent of the urchin fishery, there has been substantial algal recruitment to depths of about 20 m, expanding abalone habitat and food supply (J.D. DeMartini & K.A. Karpov, pers. obs.).

Sea otters dramatically affect the distribution, abundance and size structure of abalone populations (Hines & Pearse, 1982). Hunted almost to extinction in the eighteenth and nineteenth centuries, otters have slowly expanded their range since they were protected in 1911. Within the established otter range (Fig. 26.1), abalone are restricted to crevices and thus are highly dependent on the physical structure of the habitat; abalone are virtually absent from sedimentary rock substrates which do not provide crevices. Hines & Pearse (1982) estimate a very high turnover rate (1–3 years) in a kelp forest near Monterey; this estimate depends also on high rates of recruitment and growth. Sea otters have been transplanted to San Nicolas Island in southern California in an effort to secure the status of this mammal potentially threatened by oil spills in central California. However, most of the transplanted otters have left the island, and the future of this effort is not clear (E. Ebert, pers. comm.).

Outside the sea-otter range, predation is less important. Hundreds of hours of observations on the north coast have yielded few examples of predation; most of these involved a variety of asteroids feeding on large abalone (J.D. DeMartini, pers. obs.). Accordingly, Smith (1972) estimated an annual turnover rate (finite mortality rate) of 0.05 based on a length–frequency distribution from Mendocino County. Southern California supports a variety of abalone predators which collectively prey upon a wide size range of animals, but none are as dominant as the otter. These include asteroids, octopuses, crustaceans and fishes (Cox, 1962; Hines & Pearse, 1982; Tegner & Butler, 1985, 1989; Tegner *et al.*, 1989). Several of these predators, e.g. the spiny lobsters (*Panulirus interruptus*), are generally not found north of Point Conception, a major biogeographic boundary. Tegner *et al.*, (1989) estimated a natural mortality of 0.15 from five years of length–frequency distributions on Santa Rosa Island.

Growth rates, reproduction, recruitment and population structure

Long-term tagging programmes have been carried out in two areas, on Santa Rosa Island in southern California (Haaker *et al.*, 1986, unpublished data; Tegner *et al.*, 1989) and at several locations within Mendocino and Sonoma Counties in northern California (J.D. DeMartini, unpublished data). A total of 809 animals tagged at Santa Rosa Island between 1978 and 1981 yielded von Bertalanffy growth parameters of $K = 0.270$ and $L_\infty = 200.1$ mm. At this growth rate, 8.0

years are required to reach a sport minimum size of 178 mm and 15.0 years for a commercial minimum legal size of 197 mm. In the north, 1797 animals were tagged and recovered for 16 one-year intervals between 1971 and 1977 at five sites. The modal values were $K = 0.217$, $L_\infty = 192.4$, and time to sport minimum legal size was 11.8 years. Both set of estimates are based on considerable variability; the range for time to sport minimum legal size was 5.4–10.8 and 7.9–25 years for Santa Rosa Island and the north coast, respectively. Nevertheless, the data suggest that there are important differences in growth rates between southern and northern California.

Reproduction on the north coast is tightly linked to the onset of algal production (Giorgi & DeMartini, 1977; Ault, 1985). Ault's study clearly demonstrated the importance of the food regime in achieving sexual maturity, in apparently hastening gamete development and in increasing fecundity. Ault estimated that 120 days are required for the completion of the reproductive cycle in the field. This plus the seasonality of food production suggests that spawning in northern populations is temporally limited. Leighton (1974) found that red abalone collected from Estero Bay in Central California could be induced to spawn in the laboratory every month of the year. Similarly Price (1974), who studied animals collected near San Diego in Southern California where food was never limiting, detected spawning during at least three periods of the year. The size of the gonads in Price's study remained high throughout the year, suggesting that spawning may occur continually at a low level in this region.

Reproductive patterns are likely to affect recruitment rates and population structure. Recruitment rates were measured on Santa Rosa Island (Tegner *et al.*, 1989) and inferred to be high in central California to account for the high productivity observed (Hines & Pearse, 1982); no data are available for northern California. A comparison of the length–frequency distributions of emergent (animals visible without the need to turn rocks or use a light) abalone from Santa Rosa Island (Tegner *et al.*, 1989) with Mendocino and Sonoma Counties (Parker *et al.*, 1988) suggests that recruitment is much more regular in the south (Fig. 26.2). The northern size distribution is dominated by large, old animals, a majority of which are vulnerable to the fishery. These distributions are significantly different (Kolomogorov-Smirnov test, $p < 0.001$). The average size of 183 mm for northern red abalone contrasts sharply with the average of 75 mm for a central California population within the otter range, where animals of sport minimum legal size are rare despite protection from fishing (Hines & Pearse, 1982).

THE CALIFORNIA COMMERCIAL FISHERY FOR RED ABALONE

Landing summaries of commercial fisheries used in this chapter refer to south-central California, the area from San Diego through Santa Cruz Counties, and the San Francisco commercial area, San Mateo County to Point Lobos in San Francisco County and the Farallon Islands (Fig. 26.1). Landing statistics for 1973–88 were obtained from both published and unpublished compilations of California Department of Fish and Game (CDFG) market landing receipts (McAllister, 1975, 1976; Pinkas, 1977; Oliphant, 1979; Oliphant *et al.*, 1990). Red abalone landings for 1931–51 were taken from Cox (1962) and are not divided by subarea of California;

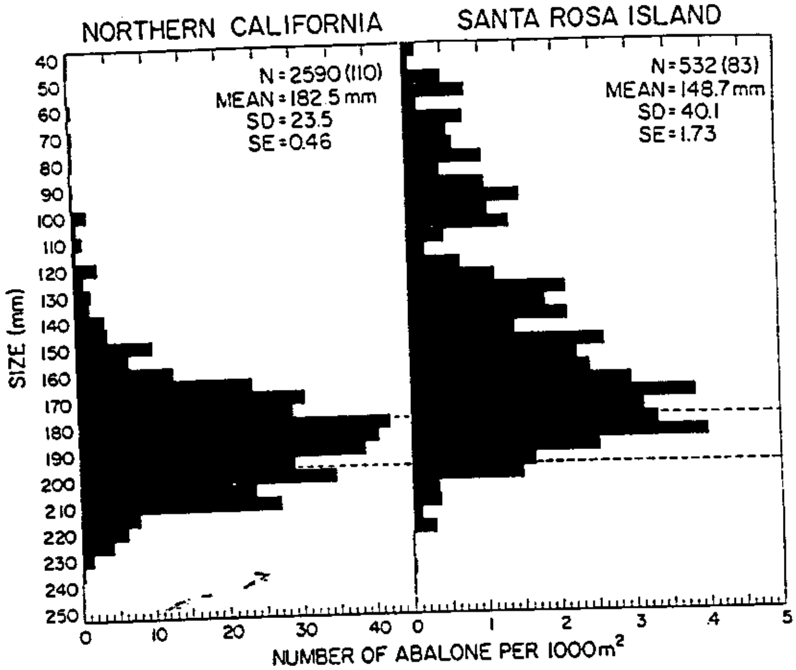

Fig. 26.2 Size–frequency distributions of emergent red abalone found in northern California (Mendocino and Sonoma Counties, Parker *et al.*, 1988) and southern California (Santa Rosa Island, Tegner *et al.*, 1989). The dashed lines indicate sport (178 mm) and commercial (197 mm) minimum legal sizes.

for 1951–72 abalone landings were not delineated by species in published catch bulletins and were obtained for south–central California from an unpublished report by Burge *et al.* (1975). Abalone landings reported in the San Francisco area were not delineated by species prior to 1973 and were assumed to be reds since black (*H. cracherodii*) abalone are rarely taken in this area.

Prior to 1916, red abalone stocks in California could be described as virginal, having accumulated in the recent absence of significant predation by either man (Cox, 1962) or sea otters (US Fish and Wildlife Service, 1987). From 1916 until the early 1960s, commercial harvest was focused in central California from Monterey to Point Arguello (Cox, 1962) (Fig. 26.1). The fishery slowly shifted southward after the opening of the mainland south of Point Conception and the Channel Islands in 1943. State-wide landings averaged over 900 metric tons wet weight per year from 1931 to 1968, with a peak landing of 1744 t in 1935 and a record low of 45 t in 1942 during World War II (Fig. 26.3). Management of the commercial fishery was based largely on a size limit. The CDFG assumed that an appropriate size limit, large enough to allow several spawnings but small enough that the size would be achieved within a reasonable number of years after settlement, could maintain the stocks (Burge *et al.*, 1975). Since 1968, commercial catches in south–central California have declined steadily to current levels of less than 136 t per year. Limited entry to the commercial fishery (and tighter limitations on sport

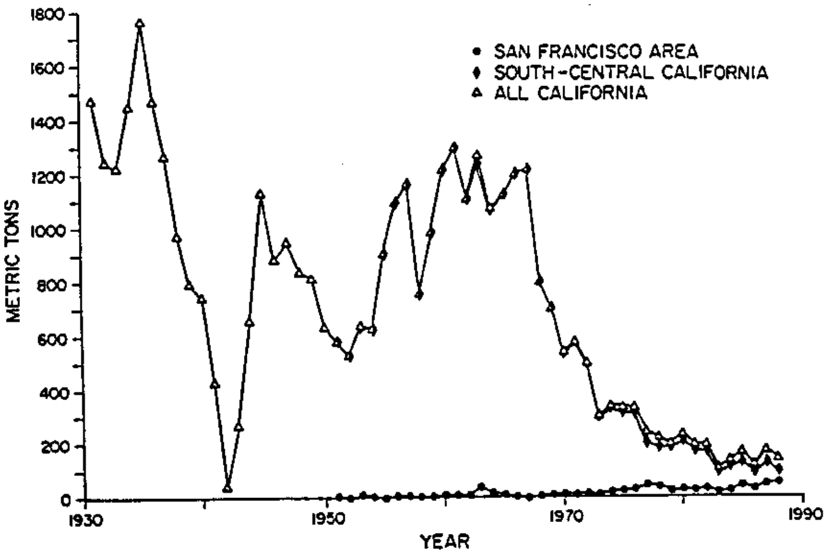

Fig. 26.3 Commercial red abalone landings from all California for 1931 to 1988 and broken down into south-central California and the San Francisco area for 1951 to 1988. The total and south-central California catches are similar because the latter comprises the vast majority of the area open to commercial fishing. See the text for further explanation.

fishermen) was instituted in 1977, but the downward trend has continued. Neither commercial catch quotas nor separate area allocations for commercial and sport fishermen have been used as management tools for red abalone in California.

The declining catch in south–central California which began in the late 1960s has been attributed to the combined effects of greatly increased commercial effort, increased natural predation as a growing sea otter population expanded southward into the commercially-productive Beckets Reef and Point Estero beds and eventually to Point Conception, effects of pollution, area closures and competition with a growing sport fishery (Bissell & Hubbard, 1968; Ebert, 1968; Miller *et al.*, 1974; Burge *et al.*, 1975; Cicin-Sain *et al.*, 1977; US Fish and Wildlife Service, 1987; Tegner, 1989; Tegner *et al.*, 1989). The decline was delayed by a major increase in fishing power. From 1965 to 1970 'dead boats' or single-diver boats using hookah without a tender replaced the less efficient hardhat divers (E. Ebert, pers. comm.). In 1968, the Radon Craft was introduced and became the vessel of choice for the commercial fishery. Boats like the Radon, using multi-hose hookah, are capable of high speed and withstanding rough seas; these allowed exploitation of the remaining virgin stocks on the Channel and Farallon Islands from the 1970s onward. Yield-per-recruit and egg-per-recruit analyses suggested that present sport and commercial legal minimum sizes allow for adequate egg production to maintain stock sizes in southern California (Tegner *et al.*, 1989; see also Chapter 20, this volume). Nevertheless, the sharp and continuing decline in landings indicates that management heavily based on minimum legal size has not been successful.

Commercial harvest of red abalone in the San Francisco area was not reported yearly prior to 1951, although Cox (1962) stated that 238 t were landed from San

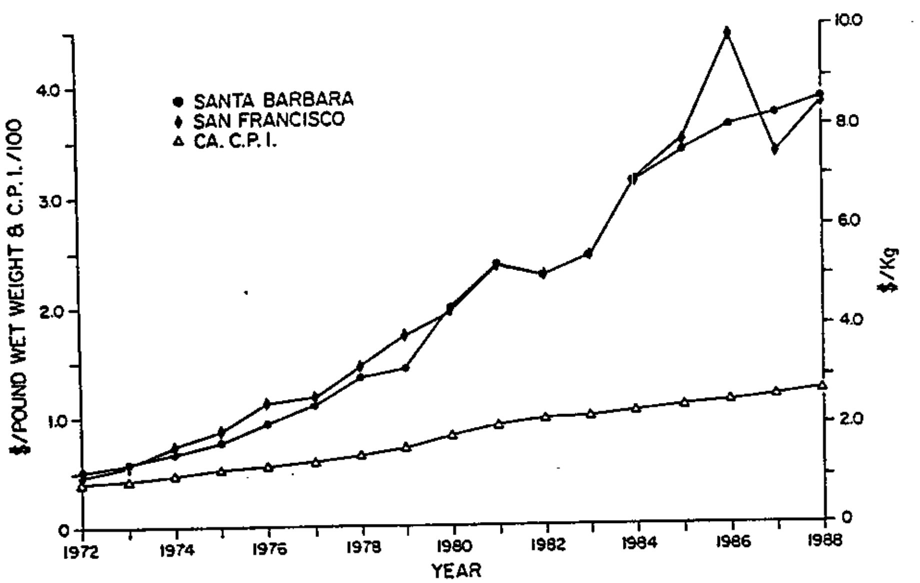

Fig. 26.4 Red abalone commercial ex-vessel price in Santa Barbara and the San Francisco area, and the California consumer price index for 1973 to 1988.

Francisco to Humboldt Bay in Northern California in the three years prior to the 1945 commercial closure north of Point Lobos (Fig. 26.1). Landings in the San Francisco area averaged only 9.6 t from 1951 through 1972. Since 1972, landings have increased to a peak of 52.7 t in 1988, which constitutes 34% of California's commercial red harvest (Fig. 26.3); most of the recent increase has been falsely reported as originating from the Farallon Islands. This increase cannot all be attributed to the small area of subtidal habitat around the Farallon Islands ($3.8\,km^2$) considering its long history of commercial exploitation. CDFG Wildlife Protection staff suspect that increased illegal commercial harvest on the north coast, especially in association with the recent sea-urchin fishery, is the cause for some of the rise in landings.

Recent increases in the landed value of red abalone show an inverse relationship to decline in state-wide catches. The fisherman's price-per-pound in the shell has increased over twice the rate of inflation as shown in comparison with the California consumer price index (CPI) from 1973 through 1988 (Fig. 26.4). In both the south-central and San Francisco areas, the price paid to fishermen increased from about \$0.50 in 1973 to over \$3.80 per pound in 1988 (\$1.10 to \$8.38 per kilogram), or an 800% increase compared to 300% increase in the CPI during the same period.

THE NORTH-CENTRAL CALIFORNIA SPORT FISHERY FOR RED ABALONE

Sport fishery statistics, currently not available from southern California, were obtained for the north-central region of the state using a combined field 'creel' and randomized telephone survey initiated in 1985. The creel was focused in Sonoma, Mendocino, and Humboldt Counties, where the largest concentrations of sport fishermen were found. Prohibited from using scuba to take abalone north of Yankee Point in Monterey County, sport fishermen are restricted to snorkling (free diving) or 'shore picking', intertidal fishing without the use of fins. The open season is April through November with July and December through March closed, and there is a daily bag limit of four abalone for holders of sport fishing licences.

During each year of the 1985–8 creel, 1600–2800 divers or shore pickers were interviewed. Data collected included size of the abalone taken, take-per-picker-day (t/p), and county of fisherman origin. In addition, 9600–15 200 north-central California households from counties within 42 km of the ocean estuaries were randomly telephoned each year. Each phone contact was asked if a household member had participated in a sport abalone fishery; the fishermen were then asked the number of days spent abalone fishing in the preceding two months, county of the fishing trip, whether the fishermen were divers or shore pickers and the species targeted.

Expanded estimates of effort (Et) in red abalone fishing days and total weight in shell (Tw) were obtained separately for divers and shore pickers for each two month period by combining creel and telephone data. Expanded estimates of effort were obtained for each two month period using $Et = N \times (Rt/Rcc) \times (1/Re)$, where N is the census value for the number of occupied households in the telephoned counties, Rt the ratio of abalone fishing days to total contacted households, Rcc the creel ratio of fishermen from telephoned counties to all areas of origin and Re an adjustment for households that admitted abalone fishing effort prior to rejecting further questions. The expanded estimates of landed weight were obtained using $Wt = Et \times Wx \times t/p$, where Wx is the average total weight of red abalone obtained using measured lengths and the length–weight regression $W = aL^b$, with $a = 0.000161$ and $b = 3.02$ (Ault, 1982).

The 95% confidence intervals (CI) were computed for each landed weight estimate using 'bootstrapping', a method developed by Effron & Tibshirani (1986). Variances for each 2-month stratum were then combined to compute a yearly CI from the relationship $CI = \pm 1.96 \times$ (standard error). Deficiencies during the pilot year of the survey did not allow an April estimate or 95% CI computation for 1985 as a whole.

More than 93% of the sport fishing trips reported during the north-central California survey occurred in northern California, with 46% and 26% in Mendocino and Sonoma Counties, respectively. Effort in days spent abalone fishing differed seasonally between divers and shore pickers in this region. During the sport season from April through November, the 1985 to 1988 average diving effort was high for all months except November (Fig. 26.5). Shore picking effort was high only from April through May, declining in August, and negligible during September through November. Analysis of take-per-picker-day (t/p) showed a similar pattern of seasonal decline for shore pickers and not divers. The decrease in effort of shore pickers reflects in part fewer low tides later in the sport season; however, the concurrent decrease in t/p is also a factor. Ault & DeMartini (1987) found significant movement of red abalone subtidally, and suggested net movement onshore during winter months and offshore during the summer in this region. If

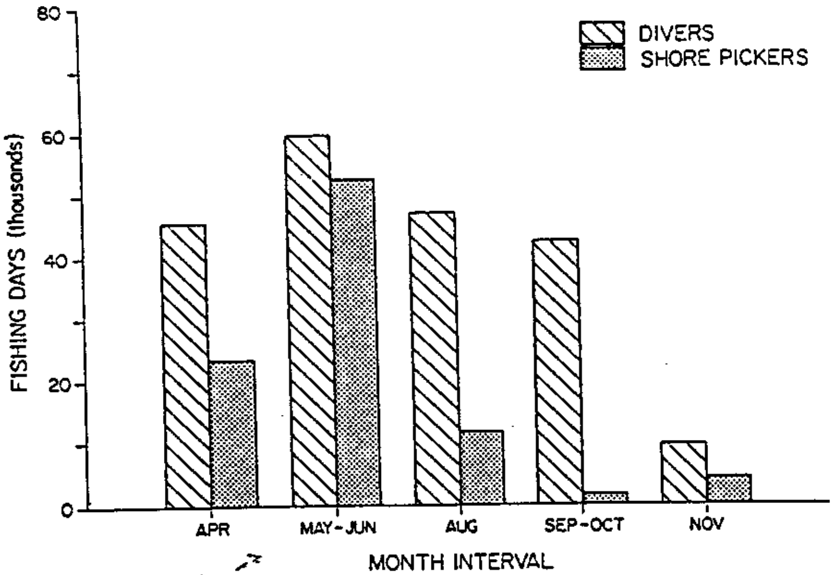

Fig. 26.5 Average effort by month interval for north-central California sport divers and shore pickers, 1985–8.

applicable to intertidal stocks, such movement could help explain seasonal differences in availability to shore pickers.

The catch for both modes of fishing combined ranged from a 1988 low of 521 ± 119 t to a high of 1550 ± 204 t in 1986. Because the data for 1985 did not include April landings, these results were not directly comparable to other years of the survey. The sport diver landings declined significantly in 1988 in comparison with both 1986 and 1987, and shore pickers consistently showed lower catches than divers in all four years of the survey (Fig. 26.6).

Parker *et al.* (1988) suggest that restricting harvesting to shore picking and free-diving protects a significant proportion of the north coast stock of fishable abalone, even in areas of heavy fishing. Nevertheless, timely management changes may be needed to reduce the level of harvest in this area, considering: (a) legal harvest by the sport fishery alone may already exceed sustainable levels for northern California with landings rivalling the commercial harvest in south-central California prior to the 1968 decline, (b) the suspected illegal commercial take, (c) lower growth rates and (d) lower levels of recruitment for Sonoma and Mendocino Counties compared with Santa Rosa Island in southern California.

CONCLUSIONS

With declining stocks in south-central California, commercial fishermen have pressured the CDFG for access to the north coast. Available population data indicate that this may be infeasible. For 11 of the 16 years of tagging data, L_∞ values were below commercial minimum legal size (J.D. DeMartini, unpublished data). The high proportion of emergent animals larger than sport minimum legal

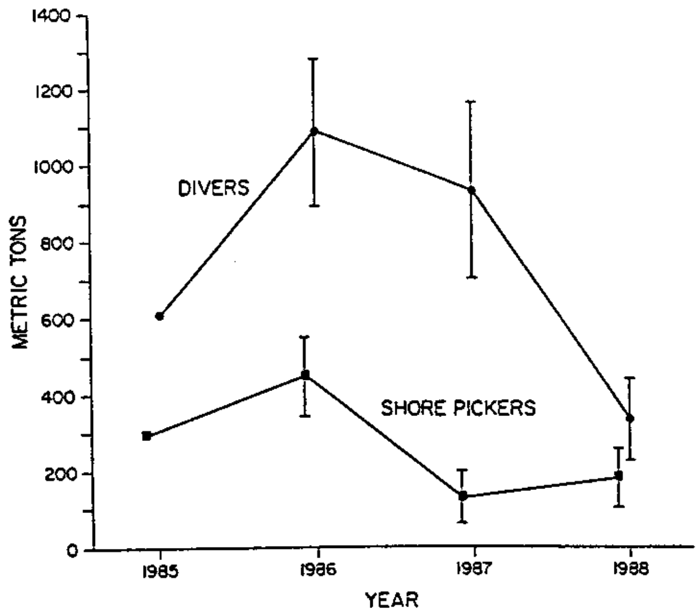

Fig. 26.6 Sport landing weight of red abalone by divers and shore pickers from 1985 to 1988 in north-central California, with 95% confidence intervals.

size (Fig. 26.2) indicates how severely this population would be impacted if the commercial minimum legal size were dropped or if sport fishermen were allowed to use scuba gear. The apparently low recruitment rates on the north coast may relate to oceanography as well as food supply; the region from Cape Blanco in Oregon to Point Conception is a region of maximum upwelling with very cool temperatures and strong offshore transport during most of the year (Parrish *et al.*, 1981). In contrast, southern California is characterized by warmer temperatures more suitable for abalone development and growth (Leighton, 1974), minimal offshore transport to disperse larvae and abundant food supplies. That we have not been able to stabilize stocks in southern California despite apparently better recruitment and growth rates underscores the need for a very conservative approach to management of remaining north coast stocks. In the absence of proven, cost-effective enhancement methods (Tegner, 1989; Tegner & Butler, 1989), the future of the fishery statewide depends upon better management of existing stocks.

We advocate

(1) immediate reduction in sport harvest through a reduced bag limit and/or seasonal closure coupled with continued monitoring,
(2) further reduction of commercial effort and establishment of mechanisms to effectively prevent illegal harvest on the North Coast, and
(3) research to refine models for stock management and to understand the ecological changes taking place in abalone habitat on the north coast caused by the sea-urchin fishery.

Emergent red abalone distributions and the fishery itself are probably recent phenomena resulting from the demise of the sea otter from most of California in the eighteenth and nineteenth centuries. The fate of both sport and commercial fisheries may be sealed if the otter range is not contained by effective zonal management. While debate continues as to whether overfishing or otters caused the decline of abalone stocks in central California (reviewed by Tegner, 1989), size–structure data make it clear that even protected abalone populations in this area cannot support a fishery today (Hines & Pearse, 1982).

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REFERENCES

Ault J.S. (1982) *Aspects of laboratory reproduction and growth of the red abalone,* Haliotis rufescens *Swainson.* Ms thesis, Humboldt State University.

Ault J.S. (1985) Some quantitative aspects of reproduction and growth of the red abalone, *Haliotis rufescens* Swainson. *J. World Maricul. Soc.*, 16, 398–425.

Ault J.S. & DeMartini J.D. (1987) Movement and dispersion of red abalone, *Haliotis rufescens*, in Northern California. *Calif. Fish Game*, 73, 196–213.

Bissell H. & Hubbard F. (1968) *Report on the sea otter, abalone and kelp resources in San Luis Obispo and Monterey Counties and proposals for reducing the conflict between the commercial abalone industry and the sea otter.* California Department of Fish and Game, Sacramento. (Senate Concurrent Resolution, 74, 1967 Legislative Session.)

Burge R., Schultz S. & Odemar M. (1975) *Report on recent abalone research in California with recommendations for management.* Unpublished report to the California Fish and Game Commission, 17 January 1975.

Cicin-Sain B., Moore J.E. & Wyner A.J. (1977) Management approaches for marine fisheries: The case of the California abalone. *Univ. Calif. Sea Grant College Program, Sea Grant Publ.*, 54.

Cox K.W. (1962) California abalones, family Haliotidae. *Calif. Dept. Fish Game, Fish Bull.*, 118, 1–133.

Deacon J. (1977) *Habitat selection and competition among abalone and sea urchins at the Sea Ranch, California.* Ms thesis, University of California, Davis.

Ebert E.E. (1968) A food habits study of the southern sea otter, *Enhydra lutris nereis. Calif. Fish Game*, 54, 33–42.

Efron B. & Tibshirani R. (1986) Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Stat. Sci.*, 1(1), 54–77.

Gerard V.A. (1976) *Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California.* PhD dissertation, University of California, Santa Cruz.

Giorgi A.E. & DeMartini J.D. (1977) A study of the reproductive biology of the red abalone, *Haliotis rufescens* Swainson, near Mendocino, Calif. *Calif. Fish Game*, 63, 80–94.

Haaker P.L., Parker D.O. & Henderson K.C. (1986) Red abalone size data from Johnsons Lee, Santa Rosa Island, collected from 1978 to 1984. *Calif. Dept. Fish Game, Mar. Res. Tech. Rpt*, No. 53.

Hines A.H. & Pearse J.S. (1982) Abalones, shells and sea otters: Dynamics of prey populations in Central California. *Ecology*, 63, 1547–60.

Leighton D.L. (1966) Studies of food preference in algivorous invertebrates of Southern California kelp beds. *Pac. Sci.*, XX, 104–13.

Leighton D.L. (1974) The influence of temperature on larval and juvenile growth in three species of Southern California abalones. *Fish. Bull., US*, 72, 1137–45.

McAllister R. (1975) California marine fish landings for 1973. *Calif. Dept Fish Game, Fish Bull.*, 163, 1–53.

McAllister R. (1976) California marine fish landings for 1974. *Calif. Dept Fish Game, Fish Bull.*, 166, 1–53.

Miller D.J., Geibel J. & Houk J. (1974) Results of the 1972 skin diving assessment survey. Pismo Beach to Oregon. *Calif. Dept. Fish Game, Mar. Res. Tech. Rpt.* 23, 1–61.

North W.J. & Pearse J.S. (1970) Sea urchin population explosion in Southern California waters. *Science*, 167, 209.

Oliphant M. (1979) California marine fish landings for 1976. *Calif. Dept Fish Game, Fish Bull.*, 170, 1–56.

Oliphant M.S., Gregory P.A., Ingle B.J. & Madrid R. (1990) California marine fish landings for 1977–1986. *Calif. Dept. Fish Game, Fish. Bull.*, 173, 1–52.

Parker D.O., Haaker P.L. & Henderson K.C. (1988) Densities and size compositions of red abalone, *Haliotis rufescens*, at five locations on the Mendocino and Sonoma County coasts, September 1986. *Calif. Dept Fish Game, Mar. Res. Div., Ad. Rpt.* No. 88–5.

Parrish R.H., Nelson C.S. & Bakun A. (1981) Transport mechanisms and reproductive success of fishes in the California Current. *Biol. Ocean.*, 1, 175–203.

Pinkas L. (1977) California marine fish landings for 1975. *Calif. Dept. Fish Game, Fish Bull.*, 168, 1–55.

Price P.S. (1974) *Aspects of the reproductive cycle of the red abalone*, Haliotis rufescens. Ms thesis, San Diego State University.

Smith S.V. (1972) Production of calcium carbonate on the mainland shelf of Southern California. *Limnol. Oceanogr.*, 17, 28–41.

Tegner M.J. (1989) The California abalone fishery: Production, ecological interactions, and prospects for the future. In *Marine Invertebrate Fisheries: Their Assessment and Management* (Ed. by J.F. Caddy), pp. 401–20. Wiley, New York.

Tegner M.J., Breen P.A. & Lennert C.E. (1989) Population biology of red abalones, *Haliotis rufescens*, in Southern California and management of the red and pink, *H. corrugata*, abalone fisheries. *Fish. Bull. US*, 87, 313–39.

Tegner M.J. & Butler R.A. (1985) The survival and mortality of seed and native red abalones, *Haliotis rufescens*, on the Palos Verdes Peninsula. *Calif. Fish Game*, 71, 150–63.

Tegner M.J. & Butler R.A. (1989) Abalone seeding. In *Handbook of Culture of Abalones and Other Gastropods* (Ed. by K. Hahn), pp. 157–82. CRC Press, Boca Raton.

Tegner M.J. & Dayton P.K. (1991) Sea urchins, El Niños, and the long term stability of Southern California kelp forest communities. *Mar. Ecol. Prog. Ser.*, 77, 49–63.

Tegner M.J. & Levin L.A. (1982) Do sea urchins and abalones compete in California kelp forest communities? In *International Echinoderms Conference, Tampa Bay 14–17 September, 1981* (Ed. by J.M. Lawrence), pp. 265–71. A.A. Balkema, Rotterdam.

US Fish and Wildlife Service (1987) *Final Environmental Impact Statement for Translocation of Southern Sea Otters*. USFWS, May 1987, Vol. I–III.