Near extinction of an exploited marine invertebrate

Marine extinctions within historical times are thought to be rare. Of 1321 taxa on the United States federal listing of threatened or endangered organisms (as of Ref. 3), only six have marine or estuarine phases in their life cycle, and none is a wholly oceanic finfish. Carlton1 describes four recent extinctions of non-exploited marine invertebrates; their commonality appears to be coastal habitats vulnerable to human impact — salt marshes, estuaries, lagoons, seagrass communities, and supralittoral zones. Although there are reasons to question the perception of fewer extinctions in the ocean2, the implication is that species inhabiting offshore marine habitats buffered from degradation and manipulation are more likely to be endangered by overexploitation.

In a 1994 fisheries review, Jamieson4 found no marine invertebrates to be threatened with global extinction resulting from overexploitation, despite many examples of severe depletion or disappearance of local populations. Indeed, marine invertebrates are often considered to be resistant to overfishing owing to broad ranges, high fecundities, larval dispersal and, for most benthic species, limited mobility and scattered concentrations that may provide for refuge populations. A new report by Davis et al.5 of the near extinction of the white abalone (Haliotis sorenseni), a prosobranch gastropod subjected both to commercial and to recreational harvest, suggests that a re-evaluation of management policies for certain fisheries is long overdue.

Abalones — highly prized shellfish — are found in predictable and accessible locations near stands of their macroalgal food; movement is minimal5. They are slow growing, long-lived, and have unpredictable recruitment; as a result, size-frequency distributions tend to be skewed with an accumulation of older individuals. Historically, white abalones ranged over about 8° of latitude from Point Conception, California, USA to Punta Abreojos, Baja California, Mexico. Adults are found in the open, on rocky habitat with understory kelp from depths of 26 m to at least 65 m (Ref. 5); the difficulties of stock assessment for benthic species with patchy distributions are exacerbated by this depth range where diving safety considerations minimize bottom time.

The deepest living of the five commercially exploited abalone species in Southern California, *H. sorenseni*, was harvested after the decline of the more available shallow water species, but its tender meat yielded premium value5. This resulted in an intense but short-lived fishery in which 95% of commercial landings took place in just nine years, 1969-1977. Davis and colleagues recently censused Channel Island sites in the Southern California Bight that had been surveyed in the 1970s and 1980s, and found two to three order-of-magnitude decreases in abundance. They found only three white abalones in 3.06 ha of prime habitat in 1991-1993, habitat that had supported 6120-30 600 animals 20 years earlier5.

Abalone shells offer information about population structure and sources of mortality5. 119 white abalone shells collected during the 1991-1993 surveys were predominantly large animals and only one was a recent mortality. While mortality caused by handling sub-legal animals may have caused some of the deaths, a number of the shells were larger than commercial harvestable size. Davis et al. conclude that the last major recruitment to the population was probably spawned in the late 1960s or early 1970s, and that the population is approaching extinction from natural causes. The three live animals found in the most recent survey were collected for captive breeding; unfortunately all are male.

The decline of this species appears to derive from a combination of fishery and biological considerations. The high economic value of abalones has justified extensive commercial search effort for many years, and the abundance of legal-sized animals in even distant Channel Island populations is often quite low5. The return to commercial fisheries for red abalones (*H. rufescens*), the only remaining fishery in Southern California, was US $420 per dozen animals in February 1996 (K. Henderson, pers. commun.). Recreational diving pressure is extensive and under no economic constraints.
constraints on search effort. Management relies almost completely on minimum legal size to protect spawning stock; while the size limits appeared to provide for adequate egg production, this practice does not take into account spatial dispersion, variability in recruitment, or other biological factors.

Abalones are dioecious broadcast spawners that require high concentrations of sperm and thus aggregations of adults for successful fertilization (reviewed in Ref. 9). Some species are known to aggregate for spawning, but lose that ability as densities decline to low levels. Thus, the effective population size, the number of individuals making more or less equal contributions to subsequent generations, declines more rapidly than the true population size as density declines10. Whether the zone of effective fertilization is less than a meter5 or slightly larger6 is an open question for the moment (see also Refs 8 and 9). Abalone species exhibit most of the traits that Jamieson4 suggests would characterize species vulnerable to near extinction and range reduction from overfishing: relatively large size, occurrence in a relatively restricted geographic range near human settlement, exceptional market demand to justify exploitation at very low stock densities and, associated with their typically large size, a relatively long lifespan and, consequently, normally low annual recruitment. White abalones are certainly not intertidal or shallow subtidal to facilitate capture, but their high value has apparently overridden any refuge potentially afforded by their deep distribution. Diving is an extremely efficient harvesting method on open substrate types7 and poaching appears to be a serious problem in Southern California8. On the basis of Davis et al.5, the California Department of Fish and Game closed the commercial and recreational fisheries for white abalone on 1 March 1996.

Within Southern California, white abalones were predominantly found on the Channel Islands; it is unlikely that population in Los Angeles County, CA, USA, was not sufficient to protect a coastal refuge; details of Baja California stocks are sketchy, but Guzman del Proo11 presented no white abalone data after 1970 nor a minimum legal size in his review of the Mexican fishery. Furthermore, abalone larval dispersal is relatively limited under average environmental conditions (reviewed in Refs 8 and 9); stock replenishment by distant, less impacted sources, as might be expected for species with longer lived larvae, is not a realistic prospect over multi-decadal timescales.

Disease can have potentially devastating implications for depleted stocks (e.g. Ref. 12). Withering syndrome, an apparent disease, led to the collapse of black abalone (H. cracherodii) populations in the Southern California Right over the past decade13, and it is possible that disease contributed to the decline of white abalones. One of us (M.J.T.) collected 20 freshly dead, adult white abalone shells that had no predator marks, from Farnsworth Bank offshore of Santa Catalina Island (CA, USA) in July 1990 (unpublished data). Davis et al.5 collection of adult shells also indicates that the last few large animals were not fished. However, they argue convincingly that "harvest in the mid-1970s reduced adult densities to the point that reproduction was insufficient to produce recruits regularly. If disease played any role in this population collapse, it may have only delivered the coup de grâce to an already depleted and struggling population15.

For most fisheries, population depletion leads either to management closing the fishery or to densities that are so low that further fishing is uneconomical before the situation becomes critical. White abalones exhibit most of the traits that Jamieson4 suggests would characterize species vulnerable to near extinction and range reduction from overfishing: relatively large size, occurrence in a relatively restricted geographic range near human settlement, exceptional market demand to justify exploitation at very low stock densities and, associated with their typically large size, a relatively long lifespan and, consequently, normally low annual recruitment. White abalones are certainly not intertidal or shallow subtidal to facilitate capture, but their high value has apparently overridden any refuge potentially afforded by their deep distribution. Diving is an extremely efficient harvesting method on open substrate types7 and poaching appears to be a serious problem in Southern California8. On the basis of Davis et al.5, the California Department of Fish and Game closed the commercial and recreational fisheries for white abalone on 1 March 1996.

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For most fisheries, population depletion leads either to management closing the fishery or to densities that are so low that further fishing is uneconomical before the situation becomes critical. White abalone species will require going beyond dependence on minimum size limits to ensure the survival of brood stocks at appropriate densities through periods of poor recruitment. Marine reserves or harvest refugia offer many potential benefits, but management via abalone fishery closure was not sufficient to protect a coastal population in Los Angeles County, CA, USA, from apparent poaching. Furthermore, because of limited larval dispersal, a large number of refugia would be required to conserve or enhance abalone stocks. Spatial management, where harvest levels are based on stock assessments within individual areas, is expensive and time-consuming. Whether resources are adequate enough to provide the levels of assessment and protection necessary to prevent extinction of small stocks of luxury foods in densely populated regions like Southern California is a conundrum of the 20th century.

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Longevity in the deep

Perhaps as part of our general biophilia, we have a general fascination for longevity. Maximal human lifespan seems to be about 120 years, and some turtles exceed this by 50%. Many people are aware of the bristlecone pines (Pinus aristata) being the oldest living plants, for there are several specimens thought to be approximately 5000 years old. Now Druffel and her colleagues present some fascinating data on colonial sea anemones that demonstrate that these organisms live almost as long: the order of at least 2000 years. This puts even Methuselah and his kin in the shade.

The organisms studied by Druffel et al. belong to the genus Gerardia. These colonial zoanthid sea anemones were once thought to be kin of the black corals: they carry the isotopic signature of the particular organic matter on which it feeds. This organic matter was originally produced in surface euphotic zones and its composition stores indicators of the environment of the overlying ocean mixed layer. These chemical and isotopic indicators might be used to reconstruct the past behavior of the Earth's climate system, which may hold clues to future changes5, which are of intense current interest. Fueled by the prospect of global warming, Gerardia's indicators could thus add to the cadre of paleo-indicators, from 14C in glacial ice, indicating paleo-temperature, to 13C in Patagonian peat, indicating paleo-CO2 concentrations5. Whether or not there are enough Gerardia to perform this task remains to be seen.

Another interesting aspect of the longevity of Gerardia, and its relatively small size, is that it is obviously a very slowly growing organism. This can be blamed on a relatively sparse diet, suggesting a relatively slow metabolic rate. It is noteworthy that the other longevity record holders, the bristlecones and the desert cryptobendothals, are also rather slow growers. These organisms are photosynthetic, and they seem limited more by environmental factors such as water availability, than by food per se. Nevertheless, a common feature of all these ancient organisms is that their growth is limited by the supply of food in its broadest meaning. This is reminiscent of the situation in many laboratory animals, where restricting caloric intake by 30–35% from what would be ad libitum feeding can extend an animal's lifespan (50% survival) by a similar amount. While there are numerous hypotheses to explain this phenomenon, all lead to the rather depressing notion that longevity and a good time are inversely correlated.

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