

Sea urchin fisheries and potential ecological interactions with a kina fishery in Fiordland

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Summary

This report summarises information on the world's major sea urchin fisheries and assesses potential ecological interactions with a kina (*Evechinus cbloroticus*) fishery in Fiordland.

The world's production of sea urchins was estimated to be approximately 117 000 t (whole animal wet weight) in 1995. Production is dominated by the Chilean fishery of *Loxechinus albus*, with a harvest of approximately 54 609 t in 1995. Sea urchin fisheries have a poor record of sustainability. With the exception of Chile, for which there is little available information, all the major sea urchin fisheries are in decline or have collapsed.

There is little information available on the interactions between kina, its predators and competitors in Fiordland. Although a wide range of fish and invertebrate predators consume kina, there is no evidence that any of these species control or limit populations of kina in Fiordland. Similarly, kina compete with a range of invertebrate herbivores, most notably paua (*Haliotis iris*), but there is no evidence that these interactions are of sufficient magnitude to limit populations of kina. There is no evidence that kina limit populations of paua or crayfish (*Jasus edwardsii*) in Fiordland, although information from elsewhere in New Zealand and overseas suggests that high densities of sea urchins may negatively impact on abalone populations.

1. Introduction

In this report we summarise available information on the potential ecological impact of a fishery for kina (*Evechinus cbloroticus*) in Fiordland. To provide context, the review provides a brief summary of world sea urchin fisheries. There are few specific references in the scientific literature to the ecology of kina, and its competitors and predators in Fiordland. Furthermore, the more general ecological literature on the ecology of Fiordland is largely restricted to Doubtful Sound. For this reason, we have drawn parallels to similar groups of species in other parts of the world where appropriate.

The report is structured according to questions raised by the Southland Conservancy of the Department of Conservation. It combines the two separate requests for information received. In order to be consistent with the request from the Department of Conservation, the spiny, or rock lobster, *Jasus edwardsii*, is referred to as crayfish throughout the report. The term 'large brown algae' is used in the text to refer to species of laminarian and furoid algae.

2. What kina fisheries are there worldwide?

Keesing & Hall (1998) list 32 regional fisheries for sea urchins in the world. Of these, 12 harvested more than 1000 t in 1995 (Table 1). Jurisdictional boundaries within these regions may increase the number of managed fisheries, particularly in Japan and USA. The total number of sea urchin fisheries in the world is likely to be larger than that reported in the FAO (1995) yearbook and Keesing & Hall (1998), but such fisheries are likely to be small and statistics difficult to come by.

In 1995, the total annual world production of sea urchins was 117 000t (whole animal wet weight) (FAO 1995, Keesing & Hall 1998). This represents an increase of 238% on the 49 000 t reported for 1982 (Sloan 1985). Most of this harvest is consumed in Japan and, in 1996, imports to that market were valued at US\$243 million (Keesing & Hall 1998). France is the world's second largest consumer of sea urchin roe, consuming around 1000 t per year (Hagen 1996). It should be noted that the available production statistics for sea urchin fisheries are relatively outdated and seemingly contradictory. For example, in Keesing & Hall (1998), the sum of catch by species and country exceeds the reported total world production by nearly 14 000 t. The production figures provided in Table 1 should, therefore, be interpreted as indicative only. If the declines in many of these fisheries apparent before 1995 have continued, the current world production of sea urchins from wild fisheries is likely to be smaller.

Approximately 16 species contributed to this production, but the majority of the catch was of *Loxechinus albus*, *Strongylocentrotus droebachiensis*, *S. intermedius*, and *S. nudus* (Table 1). Chile, with an annual production of 54 908 t of *Loxechinus albus*, produced nearly half the world's harvest in 1995 (Table 1). The Chilean fishery has expanded at an extraordinary rate from relatively small landings in the early 1980s. Smaller fisheries in the USA (California, Maine, Alaska, and Washington) and Japan account for most of the remainder (Table 1).

Largely undeveloped fisheries exist in New Zealand and Australia. Poor roe quality and a lack of surety in access rights has slowed development of sea urchin fisheries in these countries. In New Zealand, an experimental fishery in Dusky Sound largely failed because of poor roe quality (McShane et al. 1994). Kina continue to be harvested in most parts of New Zealand, by commercial, recreational, and Maori customary fishers (McShane 1997). The New Zealand Ministry of Fisheries currently has placed a moratorium on the issue of permits to commercially harvest kina.

3. What is the history of kina fisheries worldwide?

Sea urchin fisheries have a poor record of sustainability. Important fisheries for sea urchins have declined in France (Sloan 1985), Ireland (Byrne 1990), Japan (Saito 1992), California, USA (Kalvass & Hendrick 1997), Maine, USA (Lessing & Walker 1998), the Caribbean (Scheibling & Mladenov 1987), Washington, USA (Pfister & Bradbury 1996), and British Columbia, Canada (Keesing & Hall 1998). The causes of these declines are likely to be manifold, but most have been over-exploited and collapsed or are closed to commercial fishing. The general pattern in these fisheries is of rapid development, abetted by open access and poor management, the serial depletion of different areas within the fishery, followed by declines and sometimes collapse over periods of years up to a decade. An exception to this overall pattern of short-term 'boom and bust' is the much longer-term decline in the Japanese fishery, despite large efforts to enhance populations by releasing juveniles, closures, minimum legal size limits and a management regime that provides exclusive access rights to fishing cooperatives (Saito 1992, Hagen 1996, Agatsuma 1998).

Concerns have been expressed about the sustainability of the world's largest fishery, in Chile (Vasquez & Guisado 1992, Keesing & Hall 1998, Professor C. Moreno, Universidad Austral, Valdivia, Chile, pers. comm.). Although fisheries statistics are difficult to obtain, it appears that the very high production of the Chilean fishery is being maintained by expansion into new areas rather than sustainable harvest within traditional areas (op. cit.). The continuing strong demand for roe in the Japanese market would ensure that a decline or collapse of this fishery would renew pressure for the expansion of sea urchin fisheries in Australasia.

The management of sea urchin fisheries is an area of active research. NIWA has recently been contracted by the Ministry of Fisheries to undertake a review of the world's sea urchin fisheries and their management. An objective of this review is to provide prescriptions for the management of kina fisheries in New Zealand. This review is to be completed in early 2000.

4. What species control kina densities in Fiordland?

A wide variety of species predate kina; the range of predators narrowing as kina increase in size. Common Fiordland reef-fish, such as maori chief (*Notothenia angustata*), black cod (*N. magellanica* and *N. microlepidota*), banded wrasse (*Psuedolabrus fucicola*), scarlet wrasse (*P. miles*), girdled wrasse (*P. cinctus*), and blue cod (*Parapercis colias*) feed by picking individual prey out of foliose algae and turfing algal mats; all these species con-

sume small juvenile kina (Ayling & Cox 1982). Similarly, other common Fiordland species such as blue moki (*Latridopsis ciliaris*), copper moki (*L. aeresa*), and trumpeter (*Latris lineata*), which usually feed by taking a mouthful of turfing substrate and winnowing out prey items, also prey upon juvenile urchins (Ayling & Cox 1982). Once urchins are large enough to emerge from crevices and forage on the open substratum (at -40 mm test diameter), their likely predators are blue cod, the largest wrasses and the crayfish (Ayling & Cox 1982, Andrew & MacDiarmid 1991). The very largest kina (150 - 250 mm TD) are probably immune to predation by all but the largest crayfish (see Andrew & MacDiarmid 1991). Typically, the diet of the above generalist invertebrate predators reflects the local abundance of prey organisms, so the exact proportion of kina in their diet is unknown unless sampling is specifically carried out at the site of interest. The local abundance of these reef fishes and crayfish can be quite high, but again, without local data, their importance in controlling populations of kina is unknown.

Although these species consume kina, there is no evidence that predation by any of these species is of sufficient magnitude to limit populations of kina in Fiordland. Demonstrating that populations of kina, or any other species, are limited by predation is complex because of the many non-mutually exclusive, and probably interacting, processes that can act to reduce numbers of kina.

5. Have kina populations expanded due to a decline in natural predators and competitors?

There has been ongoing debate in the international marine ecological literature concerning the relative importance of ecological processes such as predation and recruitment in controlling the size and structure of sea urchin populations. The decline in numbers of commercial fish and lobster predators was an early candidate for study in the northwest Atlantic kelp-bed ecosystem (Mann & Breen 1972, Wharton & Mann 1981). Despite decades of investigation the true role of predators in this system is still poorly understood (Elnor & Vadas 1990), but the emerging view appears to be that predators are not the most important factor regulating the populations of urchins (Miller 1985, Elnor & Vadas 1990). The work in the Atlantic prompted work on lobster and/or reef fish predators in other reef systems around the world; in New Zealand (e.g. Andrew & Choat 1982, Andrew & MacDiarmid 1991), California (Tegner & Levin 1983, Robles 1987, Robles & Robb 1993), South Africa (Barkai & Branch 1988), in the Mediterranean (Sala et al. 1998) and off Kenya (McClanahan 1997). It is clear that in some circumstances spiny lobsters can be important regulators of benthic reef organisms, especially mussels which are often preferred prey (Griffiths & Seiderer 1980, Barkai & Branch 1988, Robles et al. 1990, Robles 1997).

Recent work in New Zealand suggests that, in protected areas where there are many large natural predators such as reef fishes and crayfish, predators can control numbers of urchins surviving the transition from crevice-bound to open substratum grazing (Cole & Keuskamp 1998, Babcock et al in press). Babcock et al. have drawn a direct link between the increases in snapper (*Pagrus auratus*) and crayfish populations and the long-term decline in kina populations in the Leigh Marine Reserve in Northland. It is likely however, that changes in the abundance of kina, and the consequent changes in habitat representation, are part of a complex set of interacting processes, including but not exclusively, increased predation. If sites in Fiordland have high abundances of these predators, they may exhibit a similar level of control. Detailed studies of kina abundance and size structure, and predator abundance and diet may suggest a regulatory function by the predators, but field experiments would be required to confirm this role (Andrew & MacDiarmid 1991).

Commercial fisheries statistics are available for crayfish from substock NSS, which encompasses Southland, Stewart Island, and Fiordland (Annala & Sullivan 1998). The latest assessment of this substock suggests that the population of crayfish larger than the current minimum legal size is approximately 320 t (Starr et al in press, reported in Annala & Sullivan 1998). This biomass is approximately 1% of the estimated pre-fishing biomass and less than 20% of that considered to be sustainable. Sensitivities of this assessment to modeling assumptions are provided in Starr et al. (in press). The ecological impact of this severe reduction in crayfish numbers is unknown.

There is no evidence that populations of kina in Fiordland have expanded due to a reduction in competition. The most likely competitor for kina, apart from conspecifics, is paua. Approximately 149 t of paua are harvested from Fiordland (PAU 5A) per annum (Annala et al. 1999). There are no estimates of pre-fishing biomass for this fishery nor assessments of the risk associated with current total annual commercial catch. Catch rates in PAU 5A have remained stable for the three years since the subdivision of PAU 5. The Ministry of Fisheries will purchase a stock assessment of PAU 5A, including surveys of paua, in Fiordland in the 1999-2000 fishing year.

6. Are high kina populations likely to be limiting crayfish and paua recruitment?

We will consider this question separately for paua and crayfish.

6.1 PAUA

There is no published evidence that high densities of kina limit paua populations in Fiordland. McShane (1997) reported that paua are abundant in Dusky

Sound, and in Chalky and Preservation Inlets, but are rare in the fiords. There have been no systematic surveys of paua in Fiordland to provide an estimate of the relative abundance and association of these species over a regional spatial scale. Without such information there is no way to judge the importance of small-scale competitive interactions relative to other ecological processes.

Unpublished research by NIWA at D'Urville Island and on the Wellington South Coast suggests, however, that there is a negative association between these species at a range of spatial scales, from that of nearest-neighbours (individuals < 2 m apart) to patterns within large 25 m² quadrats (N.L. Andrew unpublished data). Kina were not abundant at most sites surveyed for paua in Stewart Island and the Catlins coast of southern Otago between 1993 and 1999 (N.L. Andrew and J.R. Naylor, NIWA Greta Point, unpublished data). These data suggest that, for most populations of paua in these areas, competition with kina is not the prevailing ecological process. An experiment has been initiated at D'Urville Island to investigate whether there is a causal relationship between reductions in kina density and paua density at a scale of 25 m² (N.L. Andrew unpublished data). This experiment will be completed in approximately two years.

The only other evidence suggesting there is a negative relationship between sea urchins and abalone comes from New South Wales, where there is a clear negative association between abalone (*Haliotis rubra*) and sea urchins (*Centrostephanus rodgersii*) on shallow inshore reefs (Andrew & Underwood 1993). Andrew et al. (1998) demonstrated that sea urchins displace abalone on these reefs and that the large representation of sea urchin Barrens in New South Wales limits the productivity of the abalone fishery. It should be noted, however, that, in contrast to Fiordland, sea urchin Barrens cover approximately 50% of nearshore reefs in New South Wales (Andrew & O'Neill in press). Given the relatively small representation of the Barrens habitat in Fiordland, it is improbable that any interaction between kina and paua in Fiordland would be similarly important.

6.2 CRAYFISH

There is little evidence one way or the other that high kina densities are likely to limit crayfish recruitment to the benthic stage. No work has addressed this question directly, so here we describe some potential mechanisms by which it might occur and then examine the evidence that might support or refute these mechanisms.

(i) Removal of large brown algae reduces crayfish egg production and levels of puerulus settlement

Potential mechanism: Removal of stands of large brown algae at high kina densities reduces shelter available to adult crayfish which in turn leads to their emigration from the affected area or makes them more vulnerable to fishing, thereby reducing egg production and eventually the number of settling puerulus.

Evidence: The results of a controlled field experiment by Andrew & MacDiarmid (1991) suggest that the removal of large brown algae from a site has no influence on the numbers of juvenile and adult crayfish found at that site over the succeeding months.

The numbers of incoming puerulus larvae, the settlement stage of crayfish, appear to be driven primarily by the size of the offshore larval pool (Booth & Stewart 1991). Around much of New Zealand off-shore populations of larval crayfish are very low, as are adjacent levels of puerulus settlement as measured in artificial crevice collectors (Booth & Stewart 1991, Booth 1994). In only two areas are there consistent high levels of puerulus settlement along the coast, and offshore both have significant pools of larval stages. One of these areas lies between East Cape and Cape Palliser on the southeast coast of the North island and is fed by puerulus larvae from the adjacent Wairarapa Eddy (Booth 1994). The other area is Fiordland. Larvae settling here are thought to originate from Australian populations of the same species, drift across the southern Tasman Sea, and eventually settle (J. Booth, NIWA Greta Point, unpublished data).

Conclusion: The overall level of larval settlement in Fiordland is probably largely independent of the size of the resident breeding population and is highly unlikely to be affected by urchin abundance.

(ii) Removal of large brown algae reduces the amount of settlement habitat

Potential mechanism: At high densities kina can graze and remove all large brown algae from the substratum. If pueruli settle primarily on the laminae or fronds, or in the holdfasts of large brown algae, then their removal by grazing could significantly alter settlement.

Evidence: Recent observations of newly settled *Jasus edwardsii* in Australia and New Zealand indicate that pueruli naturally settle into finger-sized horizontal holes in the sides of rocks (Butler et al in press, Norman pers. obs.). Very large brown algae such as *Macrocystis pyrifera*, which can reach the surface from depths of 2-20 m may intercept the surface swimming puerulus and direct it down to the settlement substrate below (J. Booth, NIWA Greta Point, unpublished data). However, pueruli will settle successfully in the absence of large brown algae as evidenced by their occurrence on a variety of artificial habitats, including wharf pilings and walls, mussel lines, ships hulls, plywood collectors, and divers ears (Booth & Phillips 1994). Newly settled juveniles of some species of spiny lobster shelter amongst the spines of sea urchins. This behavior has never been observed in New Zealand and kina have shorter spines than urchins involved in this association elsewhere. Nevertheless, high density aggregations of kina may provide an additional microhabitat for pueruli and small juveniles.

Conclusion: The absence of large brown algae would probably not lead to any change in overall levels of settlement but may bring about subtle changes in the spatial distribution of settlement on the scale of metres.

(iii) Removal of turfing algae decreases prey availability to newly settled juveniles

Potential mechanism: Newly settled juveniles forage on a wide range of sedentary invertebrate prey, including small gastropods, amphipods and polychaete worms, that occur in high abundance in clumps of turfing species of foliose red, green and brown algae and articulated corallines. Removal of large brown algae, and smaller turfing species, from the substratum by kina grazing thereby limits the foraging microhabitat available to small, recently settled crayfish.

Evidence: There tends to be a spatial separation of kina from the complex reef structures where juvenile and adult crayfish typically reside (Andrew & MacDiarmid 1991) and these micro-habitats are often the last to be grazed by kina, even in areas of high kina abundance (A.B. MacDiarmid pers. obs.). The median foraging range of juvenile crayfish increases with their size, but for newly settled individuals is likely to be less than 2 m from shelter (MacDiarmid & Stewart in press). The smallest juveniles tend to forage on top of the rocks that form the shelter. In addition, evidence from studies of post-juvenile to adults suggests that spiny lobsters have a very variable diet and eat appropriate sized prey in proportion to those available within the normal foraging range (Doll & Phillips 1984, Jernakoff et al. 1993, J. McKoy, NIWA Greta Point, unpublished data).

Conclusion: Newly settled crayfish forage within micro-habitats least likely to be affected by kina grazing, even at high kina densities. In addition, a highly variable diet suggests that the foraging behavior of juvenile crayfish will adapt readily to changes in the abundance of potential prey species.

(iv) High kina abundance decreases prey available to juvenile and adult crayfish

Potential mechanism: Juvenile and adult crayfish prey on a range of sedentary invertebrates, including grazing gastropods. Removal of the large brown algae by kina reduces the number of prey available to juvenile and adult crayfish.

Evidence: Juvenile and adult crayfish prey upon kina and a range of grazing gastropods (Andrew & MacDiarmid 1991). The relative abundance of gastropods and other macro invertebrates may be lower within kelp forests (Choat & Schiel 1982). Removal of the large brown algae by high densities of kina creates grazing conditions suitable for a range of herbivorous gastropods, which are particularly abundant in this habitat (Choat & Schiel 1982).

Conclusions: High kina abundance is likely to maintain or increase the amount of prey available to juvenile and adult crayfish. Not only are the aggregations of kina a potential source of food to crayfish, but the areas grazed free of large brown algae are likely to support similar populations of grazing gastropods which are also prey for crayfish.

7. What fisheries species recruit into shallow subtidal waters (of Dusky Sound), and into which habitats?

Kina are abundant within Dusky Sound and form the characteristic Barrens habitat in which all large brown algae are removed (McShane & Naylor 1991, E. Villouta, DoC, Wellington, unpublished data). There are no other data for exploited species specifically for Dusky Sound. Crayfish and blue cod are found on rocky reefs and it may reasonably be inferred that they settle and recruit into the sound as well as migrating there as adults. Crayfish settle from the plankton on rocky reefs there at depths between 1 and 50 m (Booth et al. 1991). These habitats are abundant in Dusky Sound and their availability is unlikely to be limiting settlement levels of puerulus (see Section 1 c (i) above).

8. References

- Agatsuma, Y. (1998). Aquaculture of the sea urchin (*Strongylocentrotus -nudus*) transplanted from coralline flats in Hokkaido, Japan. *Journal of Shellfish Research* 17: 1541-1547.
- Andrew, N.L. and A.L. O'Neill (in press). Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. *Marine and Freshwater Research*.
- Andrew, N.L. and A.J. Underwood (1993). Associations and abundance of sea urchins and abalone on shallow subtidal reefs in southern New South Wales. *Australian Journal of Marine and Freshwater Research* 43: 1547-1559.
- Andrew, N.L. and Choat, J.H. (1982). The influence of predation and conspecific adults on the abundance of juvenile *Evechinus chloroticus* (Echinoidea: Echinometridae). *Oecologia* 54:80-87.
- Andrew, N.L. and MacDiarmid, A.B. (1991). Interrelations among sea urchins (*Evechinus chloroticus*) and spiny lobsters (*Jasus edwardsii*) in northern New Zealand. *Marine Ecological Progress Series* 70: 211-222.
- Andrew, N.L., Worthington, D.G., Brett, P.A., Bentley, N., Chick, R. and Blount, C. (1998). Interactions between the abalone fishery and sea urchins in New South Wales. Final Report to the Australian Fisheries Research and Development Corporation. 63 pp.
- Annala, J.H. and K.J. Sullivan (comp.) (1998). Report from the mid-year fishery assessment plenary, November 1998: stock assessments and yield estimates. Ministry of Fisheries. 44 p.
- Annala, J.H., K.J. Sullivan and C.J. O'Brien (comp.) (1999). Report from the Fishery Assessment Plenary, April 1999: stock assessments and yield estimates. Ministry of Fisheries. 428 p.
- Ayling, T. and Cox, G.J. (1982). *Collins guide to the sea fishes of New Zealand*. Collins, Auckland, 343 p.
- Babcock, R.C., S. Kelly, N.T. Shears, J.W. Walker and T.J. Willis (in press). Changes in community structure in temperate marine reserves. *Marine Ecological Progress Series*.

- Barkai, A. and Branch, G.M. (1988). Contrasts between the benthic communities of subtidal hard substrata at Marcus and Malgas Islands: a case of alternative stable states? *South African Journal of Marine Science* 7: 117-137.
- Booth, J.D. (1994). *Jasus edwardsii* larval recruitment off the east coast of New Zealand. *Crustaceana* 66: 295-317.
- Booth, J.D. and Phillips, B.E (1994). Early life history of spiny lobster. *Crustaceana* 66: 271-294.
- Booth, J.D. and Stewart, R.A. (1991). Distribution of phyllosoma larvae of the red rock lobster *Jasus edwardsii* off the east coast of New Zealand in relation to oceanography. In: D.A.S. Hancock (ed.), Australian Society for Fish Biology workshop on larval biology. *Bureau of Rural Resources Proceedings* 15.
- Booth, J.D., Carruthers, A.D., Bolt, C.D. and Stewart, R.A. (1991). Measuring depth of settlement in the red rock lobster *Jasus edwardsii*. *New Zealand Journal of Marine and Freshwater Research* 25: 123-132.
- Butler, M.J., A.B. MacDiarmid and J.D. Booth (in press). The cause and consequence of ontogenetic changes in social aggregation in New Zealand spiny lobsters. *Marine Ecological Progress Series*.
- Byrne, M. (1990). Annual reproductive cycles of the commercial sea urchin *Paracentrotus lividus* from an exposed intertidal and a sheltered subtidal habitat on the west coast of Ireland. *Marine Biology* 104: 275 - 289.
- Choat, J.H. and Schiel, D.R. (1982). Patterns of distribution and abundance of large brown algae and invertebrate herbivores in subtidal regions of northern New Zealand. *Journal of Experimental Marine Biology and Ecology* 60: 129-162.
- Cole, R.G. and Keuskamp D. (1998). Indirect effects of protection from exploitation: patterns from populations of *Evechinus chloroticus* (Echinoidea) in northeastern New Zealand. *Marine Ecological Progress Series* 173: 215-226.
- Elnor, R.W. and Vadas, R.L. (1990). Inference in ecology: the sea urchin phenomenon in the north-west Atlantic. *American Naturalist* 136: 108-125.
- FAO (1995) Food and Agriculture Organization (FAO) yearbook, fishery statistics, catches and landings. FAO, Rome.
- Griffiths, C.L. and Seiderer, J.L. (1980). Rock lobsters and mussels - limitations and preferences in a predator prey interaction. *Journal of Experimental Marine Biology and Ecology* 44: 95-109.
- Hagen, N. (1996). Echinoculture: from fishery enhancement to closed cycle cultivation. *World Aquaculture* Dec: 6-19.
- Jernakoff, P., Phillips, B.F. and Fitzpatrick, J.J. (1993). The diet of post-juvenile western Australian rock lobster, *Panulirus cygnus* George, at Seven Mile Beach, Western Australia. *Australian Journal of Marine and Freshwater Research* 44: 649-655.
- Joll, L.M. and Phillips, B.F. (1984). Natural diet and growth of juvenile western rock lobsters, *Panulirus cygnus* George. *Journal of Experimental Marine Biology and Ecology* 75: 145-169.
- Kalvass PE. and Hendrick J.M. (1997). The California red sea urchin, *Strongylocentrotus franciscanus*, fishery: catch, effort and management trends. *Marine Fisheries Review* 59: 1-17.
- Keesing, J. and K. Hall (1998). Review of harvests and status of world sea urchin fisheries points to opportunities of aquaculture. *Journal of Shellfish Research* 17: 1597-1604.
- Lessing M.P. and Walker C.W. (1998). Introduction to the special section on sea urchin aquaculture. *Journal of Shellfish Research* 17: 1505-1506.
- MacDiarmid A.B. and J. Stewart (in press). Nocturnal foraging and population turnover of juvenile spiny lobsters, *Jasus edwardsii* after seeding on a rocky reef. *Journal of Experimental Marine Biology and Ecology*.
- Mann, K.H. and Breen, P.A. (1972). The relation between lobster abundance, sea urchins and kelp beds. *Journal of the Fisheries Research Board of Canada* 29: 603-609.

- McClanahan, T.R. (1997). Predation and the distribution and abundance of tropical sea urchin populations. *Journal of Experimental Marine, Biology and Ecology* 221: 231-255.
- McShane P.E. (1997). A summary of commercial catch data and biological information for kina (*Evechinus chloroticus*). *New Zealand Fisheries Assessment Research Document 97/16*. 7p.
- McShane P.E. and Naylor J.R. (1991). A survey of kina populations (*Evechinus chloroticus*) in Dusky Sound and Chalky Inlet. *New Zealand Fisheries Assessment Research Document 91/17*. 21 p.
- McShane P.E., Stewart R., Anderson O. and P. Gerring (1994). Failure of kina fishery leaves bitter taste. *Seafood New Zealand* 2: 35-36.
- Miller, R. J. (1985). Seaweeds, sea urchins, and lobsters: a reappraisal. *Canadian Journal of Fisheries and Aquatic Science* 42: 2061-2072.
- Pfister, C.A. and A. Bradbury (1996). Harvesting red sea urchins: recent effects and future predictions *Ecological Applications* 6: 298-310.
- Robles, C. (1987). Predator foraging characteristics and prey population structure on a sheltered shore. *Ecology* 68: 1502-1514.
- Robles, C. (1997). Changing recruitment in constant species assemblages: implications for predation theory in intertidal communities. *Ecology* 78: 1400-1414.
- Robles, C. and Robb, J. (1993). Varied carnivore effects and the prevalence of intertidal algal turfs. *Journal of Experimental Marine Biology and Ecology* 166: 65-91 .
- Robles, C., Swectnam, D. and Eminke, J. (1990). Lobster predation on mussels: shore level differences in prey vulnerability and predator preference. *Ecology* 71: 1564-1577.
- Saito K (1992). Sea urchin fishery of Japan. In: C.M. Dewees (ed.). *The management and enhancement of sea urchins and other kelp bed resources. A Pacific Rim perspective*. California Sea Grant College, University of California, La Jolla.
- Sala, E., Boudourresque, C.F. and Harmelin-Vivien, M. (1998). Fishing, trophic cascades, and the structure of algal assemblages: evaluation of an old but untested paradigm. *Oikos* 82: 425-439.
- Scheibling, R.E. and Mladenov P.V. (1987). The decline of the sea urchin *Tripneustes gratilla*, fishery in Barbados: a survey of fishermen and consumers. *Marine Fisheries Research* 49: 62-69.
- Sloan, N. (1985), Echinoderm fisheries of the world: a review. In, B.F. Keegan and B.D.S. O'Connor (eds). *Proceedings of the Fifth International Echinoderm Conference*, Galway. Balkema, Rotterdam.
- Starr, P.J., M. Maunder, and N. Bentley (in press). Stock assessment of two New Zealand rock lobster substocks. *Draft New Zealand Fisheries Assessment Research Document*.
- Tegner, M.J. and Levin, L.A. (198-3). Spiny lobsters and sea urchins: analysis of a predator prey interaction. *Journal of Experimental Marine Biology and Ecology* 73: 125-150.
- Vasquez J.A. and Guisado C. (1992). Fishery of the sea urchin (*Loxechinus albus*) in Chile. In: C.M. Dewees (ed.). *The management and enhancement of sea urchins and other kelp bed resources. A Pacific Rim perspective*. California Sea Grant College, University of California, La Jolla.
- Wharton, W.G. and Mann, K.H. (1981). Relationship between destructive grazing by the sea urchin, *Strongylocentrotus droebachiensis*, and the abundance of the american lobster, *Homarus americanus* on the Atlantic coast of Nova Scotia. *Canadian Journal of Fisheries and Aquatic Science* 38: 1339-1349.

Table 1. Production of sea urchin by species and region for the world's major fisheries in 1995. Shown are fisheries with a production of more than 1000 t, and New Zealand. Production is metric tonnes wet weight. Table abbreviated from Keesing & Hall (1998) and sources therein, with permission.

Country (Region)	Species	Production (t)
Chile	<i>Loxechinus albus</i>	54,609
USA (NW Atlantic)	<i>Strongylocentrotus droebachiensis</i>	15,624
Japan	<i>Anthocardaris crassispina</i>	13,735
USA (NE Pacific)	<i>S. franciscanus</i>	10,086
Japan	<i>Strongylocentrotus</i> spp	9,451
Canada (Pacific)	<i>S. franciscanus</i>	6,328
South Korea	unknown	3,707
Japan	<i>Pseudocentrotus depressus</i>	3,455
Mexico	<i>S. franciscanus</i>	3,000
Canada (Atlantic)	<i>S. droebachiensis</i>	2,850
Russia	<i>S. nudus</i>	2,344
USA (NE Pacific)	<i>S. droebachiensis</i>	1,431
New Zealand	<i>Evechinus cbloroticus</i>	904