A history of the Firth of Thames dredge fishery for mussels: use and abuse of a coastal resource

L.J. Paul

NIWA
Private Bag 14901
Wellington 6241

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EXECUTIVE SUMMARY

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The green-lipped (or Greenshell[TM1]) mussel *Perna canaliculus* supported a dredge fishery in the Firth of Thames and inner Hauraki Gulf from about 1910 to the mid 1960s. Dense subtidal beds occurred on soft sediments to a depth of about 30 m. Landings were modest to 1920 and under-reported to 1930 but probably reached 500 t annually. After a dip during the Depression, they increased to 1400 t by 1940. The product was marketed mainly as fresh in-shell, but also smoked, and canned in vinegar. The main market was the greater Auckland region. Wartime events decreased landings, although canned mussels were a permitted export to prisoners of war. A three-year closure of some Coromandel beds kept landings low through the late 1940s. At this time permits were issued to dredge poor quality mussels and dead shell, but the quantity taken is unknown. In the 1950s there was a rapid rise in landings, to peak at about 2800 t in 1961. Landings then crashed to 180 t in 1965, and zero in 1969. Heavy poaching on reef-based mussels in the late 1960s and early 1970s supplied some illegal outlets. Mussel farming, trialled experimentally in the Firth in 1965 to produce a medicinal extract, began supplying supermarkets and retail outlets in the greater Auckland region with fresh mussels from the late 1970s, the supply soon exceeding demand. Underwater video and grab surveys in 2002 showed no sign of recovery of the natural beds. The dredge fishery's failure appears to have been caused by progressive fishing-out of beds, with sedimentation perhaps being a minor and localised influence. The failure of beds to recover during the subsequent 40 years is generally attributed to the loss of the most suitable substrate, the beds of existing adult mussels. In 1930 legislation was passed to allow protective leasing of seafloor areas to individual dredgers, but no leases were issued. It is possible that a comparison of heavily and lightly dredged beds would have clarified the harmful effects of over-dredging, the value of a suitable substrate, and after experimentation some form of mussel farming may have developed decades earlier than was the case. This review of the mussel fishery illustrates the impact of human activity, over a relatively short time-scale, on an important resource in one of New Zealand's most productive shallow water ecosystems.

OBJECTIVES

This report contributes to addressing the overall objective of the "Taking Stock" project which is to determine the effects of climate variation and human impact on the structure and functioning of New Zealand shelf ecosystems. To achieve this overall objective the project addresses five specific objectives. Specific Objective 2 is relevant to this report. Its aim is to assess and collate existing archaeological, historical and contemporary data (including catch records and stock assessments) on relevant components of the marine ecosystem to provide a detailed description of change in the shelf marine ecosystem in two areas of contrasting human occupation over the last 1000 years. In all, 11 separate reports contribute to addressing this specific objective, each focusing on either a different time period and associated method of inquiry (e.g. pre-European Maori period using archaeological approaches and the historical period using marine environmental history approaches – see Holm et al. 2010) or different faunal groups in one or both study regions, or New Zealand wide. This report focuses on one benthic faunal group, the green-lipped mussel (*Perna canaliculus*), which formed extensive beds on soft sediments in the inner part of the Hauraki Gulf. Over a relatively short period in the twentieth century these beds were dredged and fished out, and this report makes use of historical records and modern time series data to chart this change.

[1] Marketed since the mid 1970s under the trademarked name Greenshell Mussel[TM]

1.0 INTRODUCTION

New Zealand was the last major land mass to be settled by humans, occurring around 1280 AD (Wilmshurst et al. 2010). Consequently, New Zealand has a short and reasonably complete archaeological, historical, and contemporary record of human exploitation of marine resources compared to most other places where the earliest evidence of human impacts on marine ecosystems is difficult to discern because of climate fluctuations and changes in sea level (MacDiarmid in press). The collaborative multi-disciplinary *Taking Stock* project (ZBD200505), funded by the Ministry of Fisheries, has the overall objective of determining the effects of climate variation and human impact on the structure and functioning of New Zealand shelf ecosystems over the timescale of human occupation.

While Māori rapidly explored and settled all the main islands, the Chatham Islands to the east, and as far south as the sub-Antarctic Auckland Islands, the main centre of settlement and growth was the northern half of the North Island, including the Hauraki Gulf region, where a more benign climate allowed the cultivation of a greater range of tropically derived crops (King 2003). In the whole of the South Island the population of Māori in 1769 is thought to have been only about 6000 (Pool 1991). European settlement followed a similar pattern (King 2003). The Hauraki Gulf (Figure 1) was chosen as a case study of New Zealand wide changes as it has sufficient prehistoric, historic, and modern information about marine resource use to reliably indicate the pattern and magnitude of human impacts on the marine environment (Smith 2011, MacDiarmid in press). This report details part of the story, specifically the exploitation of mussels within the Hauraki Gulf. Historical changes within this industry, which was a moderately important regional fishery, are representative of broader relationships between human activity and marine resources in the region.

Marine mussels are easily collected, have a high nutritional value, and have been a valued seafood in many parts of the world for millennia (Dawber 2004). Three New Zealand species have been utilised since the time of early Maori occupation (Smith 2011). Two are true mussels (Mytilidae): the green-lipped mussel *(Perna canaliculus*) and the blue mussel (*Mytilus galloprovincialis*); and one is a fan mussel (Pinnidae), the horse mussel (*Atrina zelandica*).

The blue mussel occurs on intertidal rocks, and is most abundant from Cook Strait southwards. It settles naturally in some mussel farms but has limited commercial value. Although sometimes harvested as a by-product of Greenshell^{TM} mussels it is more often regarded as a problem by taking up rope space and increasing processing times (Paul 1986). The horse mussel occurs subtidally, partially buried in a muddy sand seafloor, usually from low tide to sub-tidal shallow waters of estuaries and shallow bays, and to at least 50 m depth off more open coasts. It is widespread around New Zealand (Cummings et al. 1998). Although of limited commercial value it was added to the Quota Management System (QMS) in 2004; reported annual landings have usually been less than 1 t, taken as by-catch by trawling, Danish seining, and dredging, but an unknown quantity is discarded or damaged *in situ* by this fishing gear.

The green-lipped mussel *Perna canaliculus* is the main species exploited by traditional, recreational, and commercial fisheries. As a consequence it has been extensively studied; Hickman (1983) and Jeffs et al. (1999) list or review the literature up to these dates, and there are numerous subsequent studies. Many of these studies deal with reproduction, in particular as it impacts on aquaculture; two which are relevant to the present account are Alfaro et al. (2011) and McLeod et al. (in press). The following brief summary of *P. canaliculus* biology is drawn from all these. *P. canaliculus* occurs in a variety of habitats from the low intertidal zone out to about 60 m depth. It is often found on exposed rocky shores but also subtidally in sheltered embayments where there is a firm seafloor with some hard objects providing attachment surfaces. In such habitats dense mussel beds may develop over time, mussels growing upon mussels. It is widely distributed but more common in northern and central regions of New Zealand. Studies on the life cycle and ecology of this species have generally been prompted by its potential and subsequent actual, importance in the aquaculture industry. Sexes are separate. Spawning can occur at any time of year but is usually restricted to the warmer months,

with peaks in spring and/or autumn. However, spawning and successful spatfall are not regular annual events. Planktonic larvae drift with tides and currents for 3–6 weeks, and usually have two settlement phases; the first on to filamentous algae, hydroids, bryozoans, or the byssal threads of adults, the second – after either crawling on the seafloor or free-drifting again using extruded mucous strands – on to firm surfaces. The latter may be gravel, rock, wood, or shell – including the shell of adult mussels. Subsequent growth is potentially rapid, but dependent on the quantity and quality of planktonic food (zooplankton, phytoplankton, and organic detritus), population density, and environmental factors such as temperature. Growth rates in wild populations are poorly known. The growth rate of cultivated mussels is highly variable between localities and also between years, being faster in northern areas; harvesting at about 10 cm length is done after one or two years' growth. The maximum age for *P. canaliculus* is not known.

The three mussel species have been taken by subsistence (traditional or customary) harvesting and by recreational fishers, picked from rocks or taken by shallow diving. There have been small localised commercial fisheries for blue mussel, but the main commercial species is the green-lipped mussel. The earliest, largest, and most prolonged dredge fishery occurred in the shallow subtidal waters of the southern Hauraki Gulf, and its development, collapse, and replacement by mussel aquaculture are described in this account. Particular attention is paid to the management regime under which this fishery operated.

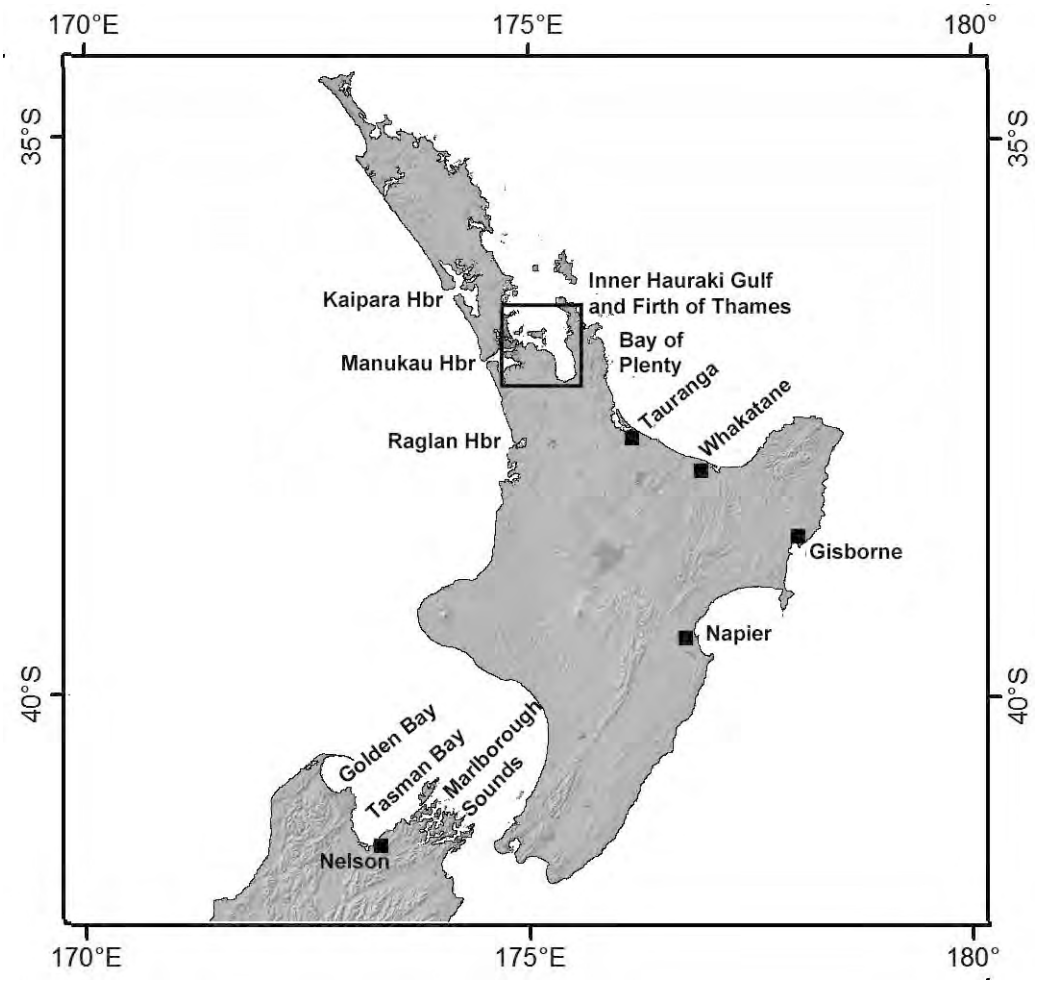

Figure 1: Northern and central New Zealand, showing localities mentioned in the text. For inner Hauraki Gulf and Firth of Thames localities see Figure 5.

2.0 METHODS

2.1 Sources of information

Much of the information has been obtained from the published Annual Reports on Fisheries[2], and all the landings data from which a catch history was constructed were obtained from this source. The earliest reports, from the late nineteenth and early twentieth centuries, contained only summarised and incomplete fisheries information, and more useful material was obtained from annotated documents on early Marine Department „Fisheries' files now held by National Archives. Information has also been collated from accounts of different aspects of mussel biology, the development, rise, and fall of this and other New Zealand mussel fisheries, and of the eventual development of mussel aquaculture in the 1970s. Among the most useful of these have been Greenway (1969), Johnson (2004), Dawber (2004), and Chisholm (2005). Two annotated bibliographies, Hickman (1983) and Jeffs et al. (1999), have also been utilised. There are numerous accounts of mussel farming, many in the grey literature, and these have been drawn upon as appropriate for the brief final account of mussel farming ventures in the Firth of Thames.

In 1944 a special section on mussels was added to the Annual Reports on Fisheries, and this was retained until the final Report in 1974; it initially comprised general comments on the fishery, later there was a division into accounts of management and research.

There is some uncertainty over the landed weights of dredged mussels, additional to the general uncertainty in reported fish and shellfish landings because of non-reporting, under-reporting, and rounding. Mussel landings are reported in sacks, and there is no definitive published statement on the weight of a mussel sack, or by how much it might vary. There are two possibilities: (1) 112 lbs, or one hundredweight, based on a coal sack weight. Values in the Fisheries Report for 1961 imply that a sack equals one hundredweight[3], and the accounts by Hickman (1989a, b, 1991, 1997) and a few other writers who use tonnes convert sack values on this basis. (2) Greenway (1969) writes "the average weight of New Zealand mussels is 150 lb per sack." Mussel sacks may have been interchangeable with the three-bushel[4] rock oyster sacks used in the Auckland region; a bushel is a volumetric measure, used widely in oyster fisheries, and if quantified is estimated at about 50 lbs. The present account assumes mussel sacks to have been three-bushel, or 150 lb. Sacks are converted to tonnes (t) in the text and in catch history figures, while the original data in sacks are tabulated in Appendix 1.

The term "bed" is used for an aggregation of mussels on the seafloor, following its use in New Zealand fisheries accounts. The term "mussel reef" is a valid alternative but in the context of this account risks confusion with intertidal or subtidal rocky reefs which bear mussels.

3.0 RESULTS

3.1 Early Maori utilization

A Maori legend tells of a battle between pipi (clams) and kuku (mussels) where the latter were lured on to sand, which clogged their tongues and forced them back to the rocks where they remain today (Reed 1963). Mussels were undoubtedly taken by Maori, particularly at locations close to rocky shores or to shallow reefs and banks in embayments and harbours. They occur within middens at

[2] Initially published as Appendices to the Journals of the House of Representatives, subsequently as Departmental Reports (Marine Department to 1971, Ministry of Agriculture & Fisheries from 1972), and as separate Fisheries Reports; the latter two reprints sometimes have revised landing values.

[3] Table 2 lists 935 sacks of mussels and scallops at Nelson, of which 879 "cwt" were scallops. The difference (56) is given in text section 14 as 56 "sacks," implying that a sack = 1 cwt. However, this might simply result from the need to balance tabular values, the fact that the units differed being overlooked.

[4] As described in many Annual Reports on Fisheries for the years in question. In later years smaller oyster "bags" were used for rock oysters.

numerous archaeological sites around New Zealand, but their thin shells are usually so fragmented that even the characteristic hinge portions are difficult to quantify in order to establish relative abundance[5]. Despite the difficulties Smith (2011) has found in a study of 77 Hauraki Gulf middens dating from over the range AD 1240–1800 that green-lipped mussels steadily decreased in percentage occurrence from 88% to 15% over the period. This was accompanied by an increase in the percentage occurrence of pipis and cockles in middens reflecting a change in Maori habitation from rocky to estuarine coastlines more conducive to crop cultivation (Smith 2011).

3.2 Earliest European usage

In 1769 Sydney Parkinson, artist on Cook's vessel *Endeavour*, wrote, "We traded with them [the Maori] for cloth, crayfish, and muscles [sic]." In 1777 William Anderson, surgeon on Cook's vessel *Resolution*, wrote "The rocks are abundantly furnish'd with great quantitys of excellent muscles [sic], one sort of which that is not very common measures above a foot in length." The latter was probably *Perna canaliculus*[6] because of the association with rocks, the large size perhaps resulting from exaggerated comparison with the more familiar *Mytilus edulis* of Europe. It may alternatively have been the fan mussel *Atrina zelandica*, colloquially known as the horse mussel, although this is unlikely because the species only occurs subtidally on a smooth seafloor.

In the late nineteenth century European settlers in coastal areas with access to mussels must have taken them privately for food, although no accounts of this use have been located. Such exploitation, however, would have been light. Some mussels would have been traded through markets and fish shops, prior to any official recording of this activity.

3.3 Early commercial landings

The earliest account of mussel harvesting in the Firth of Thames describes hand-picking from rocks at Tapu in 1909, by members of one of the small number of families involved in the mussel fishery through the twentieth century (Johnson 2004). Subsequently a dinghy, then a small motorboat was used to pull a very small dredge. A short time later a second small dredging operation started. Mussels were sold fresh or pickled in the Thames area, or dried for sale to the Chinese community in Auckland.

The first official record of a mussel fishery occurs in the Marine Department's Annual Report for 1913−14, simply noting that mussel curing and canning factories existed at Tapu and Thames.[7] Landed values were first recorded in 1923 (99 t), but it is clear from comments by Inspectors of Fisheries in the published Annual Reports, and in the unpublished port reports from which these were compiled, that in these early decades – and almost certainly later as well – there was significant under-reporting. In 1919, for example, a Thames processor stated to a Fisheries Commission hearing that he handled 10 to 12 tons of mussels per month[8], but there are no records of landings for this or adjacent years in Marine Department Reports. While some of these mussels would have still been collected by hand from shoreline rocks, it is apparent that regular dredging was already underway.[9]

[5] Dr B.F. Leach, pers. com.
[6] Which reaches at least 23 cm.
[7] Marine Department Annual Report for 1913-1914, AJHR 1914 H-15.
[8] S. Ensor, Thames fisherman and factory owner, in Minutes of evidence to Auckland Fish Commission, 1919.
[9] S. Ensor, op.cit. "[The mussels] come from right down the centre of the Gulf [Firth], from Puru to Tapu. We use a mussel dredge, $2^1/_2$ feet across the mouth. You could call it a mussel trawler."

Inner Gulf and Firth mussels were considered, somewhat indirectly, in evidence supplied to a 1919 Fisheries Commission enquiring into the general state of New Zealand's fishing industry.[10] The Commission Report's coverage of mussels dealt mainly with the potential impact of trawling on the beds. A distinction between green-lipped mussels and horse mussels was not always made.[11] The consensus of evidence from fishers and an Inspector of Fisheries was that most trawls skimmed above the seafloor and did little harm to green-lipped mussels, certainly no more than dredging did, and that light trawling which scattered the adults might encourage the young mussels to grow larger and to form new beds. Horse mussels, on the other hand, being more fragile and embedded in the seafloor, were more likely to be broken up by trawls. However, this was only conjecture. Some trawler-men stated they avoided mussel beds when possible. No decrease in "mussel" (presumably green-lipped mussel) abundance was recorded.

3.4 The 1920s: a fishery develops

Development of the hand-picked and dredge fishery through the 1920s cannot be quantified. At this time the only landings data for fish and shellfish were collected by Fisheries Inspectors in the major ports during the course of their general duties, and were variable in coverage and quality[12]. Landings by port and species were not published in the Annual Report on Fisheries until 1931, and even these were still based on records provided voluntarily by fishermen and fish markets, augmented by information from Inspectors. It was not until the outbreak of WWII and stricter government control of industries that a formal structure for collecting fisheries statistics was established. Landings of mussels in the 1920s are clearly underreported; there are no data for some years, and a few landings are reported as "cases" of unknown weight (usually mussels to be canned), in addition to sacks. The most likely estimates of landings for this decade show a fluctuating rise from about 100 t annually to more than 500 t (Figure 2). Most mussels were sold fresh locally and in Auckland, while considerable quantities were cured and sent to inland towns and as far south as Gisborne and Napier. Canning also continued.

[10] Report of Fisheries Commission, 1919. Appendix to the Journals of the House of Representatives, H-28.
[11] The crushing of horse mussel beds continued for several decades, trawlers and Danish seiners taking advantage of snapper aggregating to feed on the broken shellfish to make larger catches (Anecdotal reports to author).
[12] In his Annual Report to 31 March 1930, A.E. Hefford, Chief Inspector of Fisheries, wrote: "Unfortunately, we are still without the means of obtaining fishery statistics in a systematic and comprehensive manner, and it is to be observed that the returns which reach this office vary considerably in their approximation to accuracy."

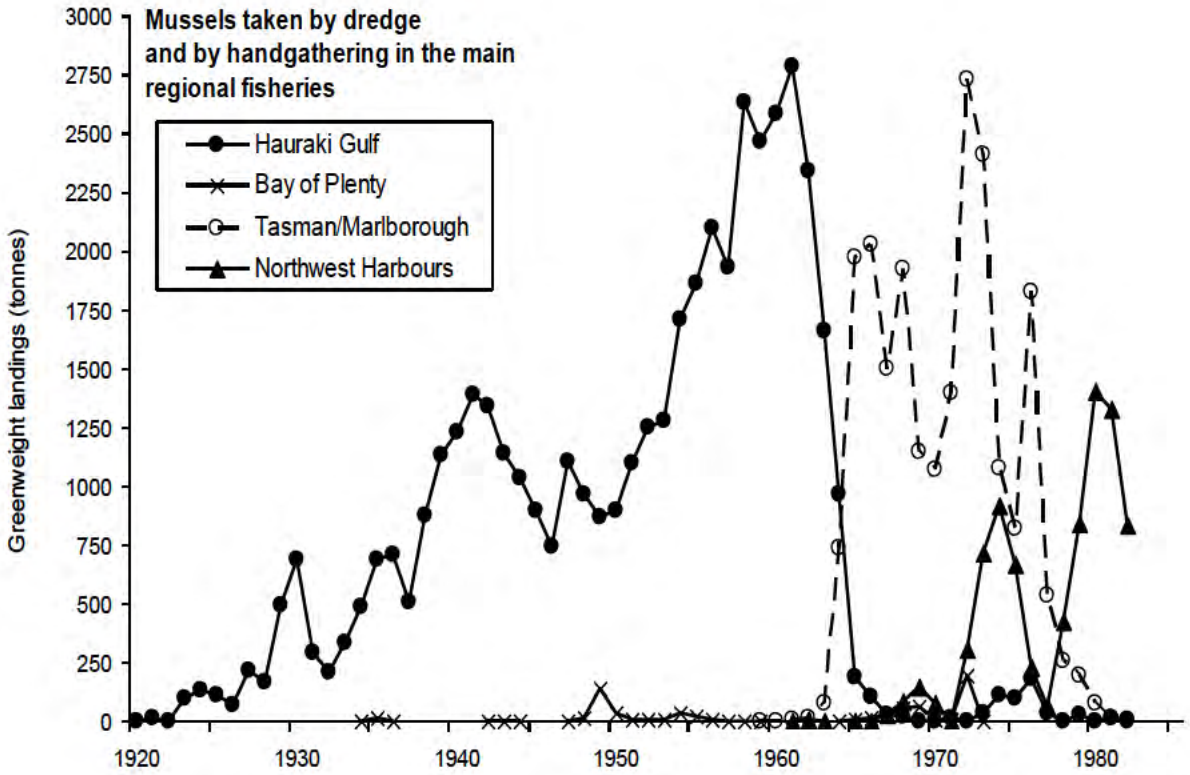

Figure 2: Recorded landings from natural populations of green-lipped mussel, *Perna canaliculus*, in the main New Zealand fisheries, based on data in Annual Reports on Fisheries. Most were taken by dredge, with some collected by shoreline handpicking. Hauraki Gulf landings are into the ports of Thames, Coromandel, and Auckland; dredge vessels usually landed into the ports where their owners' factories were situated, rather than the nearest port to the fishing grounds. Very small (to 6 t) and infrequent handpicked quantities were landed at Whangarei. The Bay of Plenty landings are from Tauranga and Whakatane, outside the Hauraki Gulf study area. Northwest Harbours are Kaipara, Manukau, and Raglan. Small (to 200 t) and/or intermittent fisheries are not shown: east Northland from 1968, Napier from 1928, the Wellington coast from 1963, and in the South Island Kaikoura, Lyttelton, and Bluff from about 1970.

Dredge size and design undoubtedly changed over time, the size depending on the size of vessel and lifting gear, the design with experience. The earliest dredges were small, the first note being of a 2 ft 6 in. (0.75 m) dredge in the 1919 Commission Report. These would have been towed by a launch plus barge, with winch and handling room on the latter, an example being the *Rosa* used by the Strongman brothers in 1925 (Pepper 2005). Their new dredger *Roa* built in 1928 initially dragged two small dredges before changing to a single large dredge (Johnson 2004). Subsequent accounts only briefly mentioned "improved efficiency," until Reid (1969) described the two dredge types used in the late 1950s, as the fishery approached its peak. Named for the two pioneering and prominent families in the industry, they were similar in basic construction, comprising a bag of strong wire mesh behind a rectangular mouth of flat iron, the upper and lower mesh surfaces being joined by chain to increase flexibility. They differed mainly in their attachment to the towing warp, and consequently the way in which they moved over the seafloor. On the Strongman dredge the towing points were at the midpoint of the mouth's side uprights, and during normal towing the mouth would be tilted slightly upwards. The dredge would move lightly over the seafloor, and was believed to take only the upper portion of mussel clusters, or elevated clusters. The Gundlock dredge had towing points at the top of the side uprights, which allowed the mouth to remain upright or tilted slightly downwards. It scooped more heavily into the seafloor, and was more efficient at taking entire mussel clusters and scattered mussels directly on or embedded in the substrate. Although the Gundlock dredge worked only one way up (the

Strongman dredge was symmetrical and could work upside-down) it was more efficient, but was considered by Reid (1969) to damage the seafloor sufficiently to prevent re-establishment of beds. The two Gundlock dredges seen by Reid were 2.2 m and 2.7 m wide, size dictated by the towing power of two vessels. Dredging was usually done with the tide, mainly to allow current pressure to bow the towing warps ahead of the dredge downwards and keep it from lifting (Reid 1969).

Loaded dredges were swung aboard the vessel (Figure 3), the mussel clumps were separated, hosed with seawater and scrubbed clean when necessary, then shovelled into large sacks or smaller wooden crates. Dredging and processing procedures are illustrated in Anon. (1963).

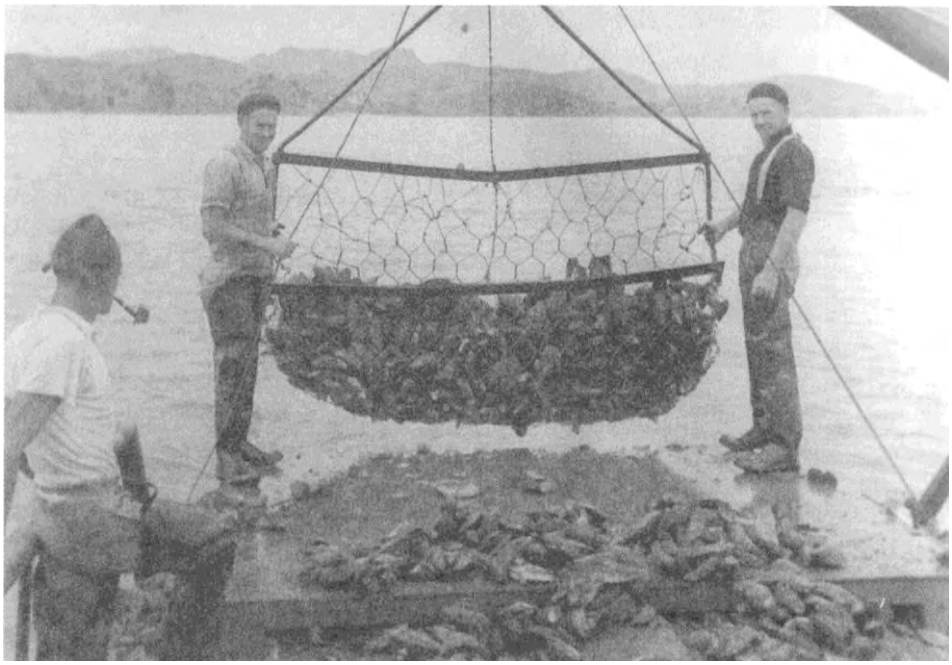

Figure 3: A mussel dredge being lifted aboard the vessel *Roa*. Based on the description by Reid (1969) this appears to be a Gundlock style dredge. Photograph by Jack Strongman, courtesy of the Strongman family.

The earliest beds worked were inside Coromandel Harbour and in the island channels outside the harbour entrance. The fishery involved only a few vessels; by the late 1920s there were two or three full-time dredgers plus one or two part-timers, based at Auckland, Thames or Coromandel. Although the beds were considered to be extensive and the fishery capable of considerable expansion, it was also recognised that localised depletion was occurring. In 1924 a full-time fisher applied for exclusive rights to a Coromandel bed, on the grounds that he could work it on a sustainable basis by dredging portions of it in rotation, while under the existing open access regime it could be easily fished out. The application was declined. In 1929 a similar request was made for an area outside the harbour (from Moturua Island to Deadman's Point) to be leased as an exclusive mussel dredging area, on the basis that the lessee would "farm" the beds in a sustainable way instead of cleaning them out and moving on. Maori would be granted continued free access to any shellfish within the leased area. This was approved by the Minister of Marine, and in January 1930 an Order in Council stated that mussels would be subject to the provisions of the Fisheries Act 1908 as it applied to artificial oyster beds, thus allowing areas to be leased for exclusive mussel fishing.[13] The Marine Department remained cautious, however, recommending that mussel fishers take out a licence and make returns of quantities landed. It also noted that the pressure for such an area came from the canning industry, that greater quantities of mussels were taken for the fresh market, and that "infringement" (presumably poaching) might be a

[13] Documentation on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1924–1938, National Archives, Wellington.

problem. There is no record of any lease being taken out, but it is noteworthy that "mussel farming" was under consideration at this early date.

By the end of the 1920s it was clear that localised over-exploitation was occurring. In his Annual Report for 1929−30, the Chief Inspector of Fisheries wrote, "In certain localities mussel-beds have already been worked out by commercial operations about which the Department had received no information until complaints were made regarding the depletion of the stocks. The returns [supplied] are by no means exhaustive and the total figure must be considerably higher." However, he was optimistic on the fishery's future, "The survey of the mussel beds in the Hauraki Gulf, which are of great extent and of considerable commercial value, is a task which still remains to be undertaken."[14]

3.5 The 1930s − Steady growth and powdered soup

During the 1930s reported landings increased from 400 to 1200 t, although they dipped to about 200 t in 1932 (Figure 2) because of the general decline in retail activity during the Depression. The main product continued to be fresh in-shell mussels marketed through wholesale depots and fish shops; canning carried on, and small quantities were dried and smoked. Dehydrated soup powder was produced, and anticipated to be a valuable export commodity.

There were differing opinions on the state of the resource and the way it should be harvested. Only a few vessels worked the mussel beds − an average of three, with one or two part-timers − probably with some fishers handpicking. Some fishers worked within small areas until the beds were essentially exhausted, while others fished beds lightly and left them to recover for some years. The latter's complaints of the potential for more than localised depletion were not accepted by the Marine Department, partly for lack of clear evidence, and partly from a belief that the beds in general were well maintained and in some cases were "matted and congested" and would benefit from being worked.[15] The Department maintained its broader intention of bringing the whole fishing industry under some form of licensing control, with the likelihood that this would properly control the mussel fishery. Within this fishery those most concerned about over-exploitation tended to be the cannery owners, perhaps because they had the greatest financial investment. The fishers themselves probably felt able to move into other fisheries if mussels became scarce, and many most likely did so when the demand for finfish increased or seasonal abundances of finfish occurred. Those who owned the dredging vessels had also diversified, some into other fisheries, some by transporting freight and passengers between the ports of Auckland, Thames, Coromandel, and smaller landing places in the region. The *Roa*, for example, took mussels from Coromandel to Auckland, returning with loads of general freight. Heavy freight, livestock and vehicles were transported on barges towed by the dredgers (Pepper 2005).[16]

3.6 The 1940s − War, bed closures, and fertiliser

Landings reached 1400 t in 1941, then for a variety of reasons declined to about 900 t by the end of the decade (Figure 2). The Second World War had several effects. There was a loss of men to the Armed Forces, and at least one of the main dredgers, the *Roa* (Figure 4), was transferred to the Navy for general patrol duties, returning in 1946 (Johnson 2004). On the other hand, canned mussel chowder became an approved item that could be sent to New Zealand prisoners of war overseas.

Fishing effort, as number of vessels, remained fairly constant through the 1940s at two to four fulltime vessels (average 2.3), and usually one part-timer. This was slightly less than during the

[14] A.E. Hefford, Report on Fisheries for the year ended 31st March 1930.
[15] Note by C. Daniel, Senior Inspector of Fisheries, Auckland, on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1924–1938, National Archives, Wellington.
[16] Conversely, in the 1950s, freight barges and vessels usually engaged in other activities briefly dredged for mussels (Johnson 2004).

1930s, although the dredges may have become larger and more efficient in terms of mussel catch per haul.

There was, in fact, some concern expressed by the owner of one mussel packing company that dredges were destroying more mussels than were being caught; this was rejected by local Fisheries Inspectors, on the rather uncertain grounds that dredges were towed at only half a knot.[17] Another concern was that poor quality mussels were being harvested during the spawning season, and that although this company observed a voluntary closure other harvesters did not; a general closure should be enforced. This was rejected on the grounds that small mussels – presumably the new spat – would be "wiped out" by heavy fishing on the first day of the new season (despite the reality that this would in fact occur at any time of the year). However, the Department did recognise that mussel beds in the vicinity of Coromandel were being fished out, and in 1945 introduced a three-year closure of these beds, recommending that prospecting for new beds be undertaken in other areas of the Firth and inner Gulf. This closure was partly responsible for the decline in landings in the mid 1940s.

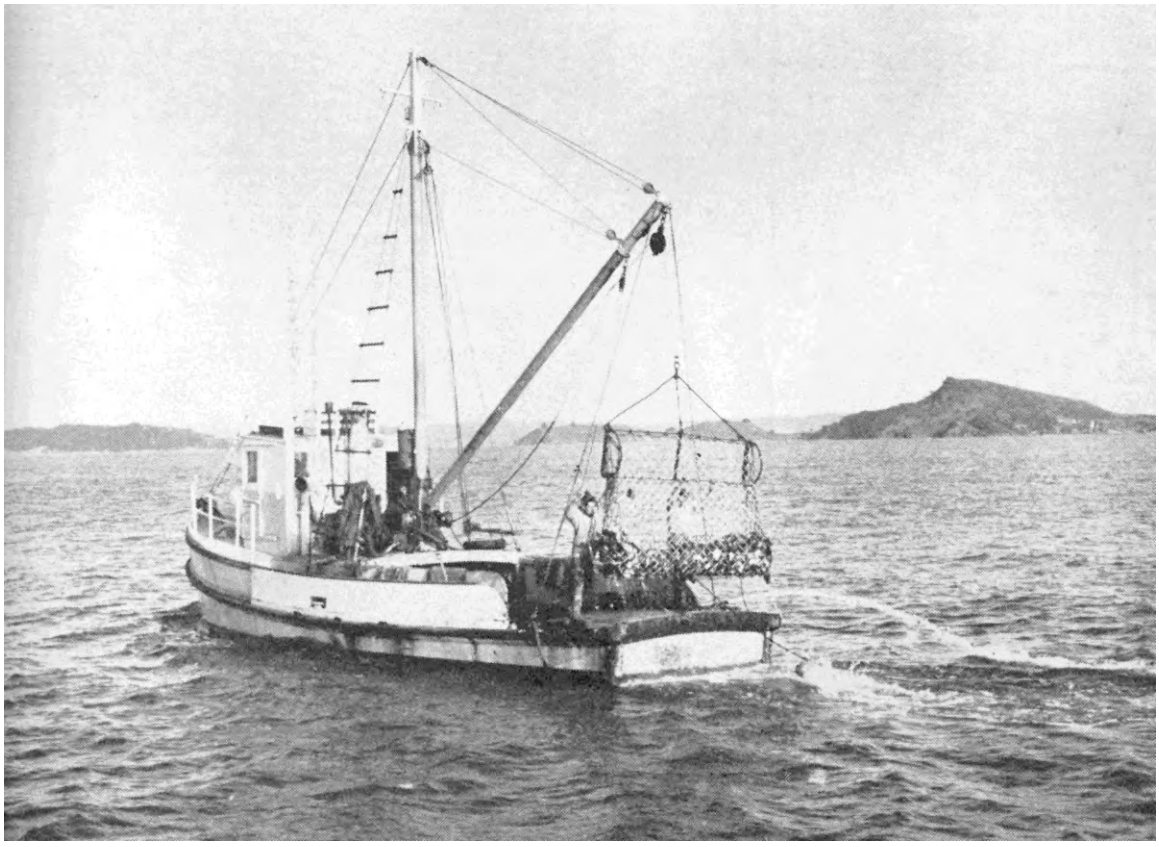

Figure 4: The mussel dredger *Roa* in the Firth of Thames. Source: From The Weekly News, 14 August 1963, courtesy Hocken Collections, Uare Taoka o Hakena, University of Otago.

From the mid 1940s there were increasing comments in Marine Department files on a decline in "quality" of the mussel beds outside and to the south of Coromandel Harbour. These comments refer both to a diminishing quantity of mussels in some areas, and to the lower quality of those mussels which were still present. This drop in quality was almost certainly additional to the well-known seasonal post-spawning drop in condition, when landings from many beds were temporarily suspended. One explanation put forward was that more silt was being deposited from flood waters as a consequence of forest clearance in catchments draining into the Firth, the area most affected being

[17] Notes on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1924–1938, National Archives, Wellington.

to the west of the main channel between Thames and Coromandel.[18] However, in other areas of the Firth and eastern inner Gulf the beds were clearly not depleted, and it was suspected that the poorly-conditioned mussels were a consequence of local over-crowding within some beds.[19]

In the late 1940s two companies were licensed to dredge the areas of poor-quality mussels and accumulations of shells a little distance offshore around the southernmost Firth, from Orere Point to Tapu, to produce fertiliser and shell lime. It is not recorded how long they operated, and it is assumed that their landings are not incorporated with the landings of edible mussels.[20] In the early 1960s shells from processed mussels, i.e., those not sold in-shell were crushed for lime fertiliser (Anon. 1963). It is not recorded how long this activity had lasted, but it seems unlikely that shells were routinely returned to the seafloor in any quantity.

3.7 The 1950s – The mussel fishery booms

In the 1950s mussel landings rose steeply and steadily, from about 900 t to about 2500 t (Figure 2). Most of this increase was taken by the same vessels that had worked during earlier decades. In the late 1950s some additional vessels received mussel dredging licences, but they apparently did not work full time and may have contributed little to total landings (Johnson 2004). There is little comment on the state of the fishery in the Marine Department's Reports, and it is possible that too much faith was still placed on control by licensing[21], together with an acceptance that localised depletion of beds, particularly off the eastern Firth coastline, would simply force dredgers to work further afield and more rationally exploit the whole inner Gulf on a self-regulating rotational system.[22] Commercial demand for the product, as fresh in-shell mussels, remained very strong.

[18] Note by E. Gilliver, Coromandel Inspector of Fisheries, on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1942–1949, National Archives, Wellington.. "It has been suggested that as a result of bush felling inland, in recent years, more soil has found its way down to the sea and deposited on these beds, and has no food value for the mussels – in fact it helped to wipe the beds out." [1944 and 1945]

[19] Note by E. Gilliver, Coromandel Inspector of Fisheries, on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1942–1949, National Archives, Wellington.file. "The dredging of these deteriorated mussel beds may have a beneficial effect so far as thinning out these beds, but as to whether it would improve the quality of the mussel would to my mind be a matter of doubt." 1945

[20] Notes on Marine Department file, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1942–1949, National Archives, Wellington.. Not mentioned in Annual Reports on Fisheries, and from the absence of any further comments on file or in any reports the activity was probably not great and probably did not extend over many years.

[21] The recorded increase in licensed mussel dredging vessels in the late 1950s might in part result from administrative ambiguities in recognising licensed vessels. During the 1950s licences were revoked at year's end (Dec. 31) when vessels had done little or no fishing that year, with the recorded number representing those licensed during the year. In 1959 the recorded number changed to vessels engaged as at 31st December (Annual Reports on Fisheries). The effect of this is unclear, but the 1959 Report states "No comparison therefore is made between the [values] for 1959 and those for previous years."

[22] Note by E. Gilliver, Coromandel Inspector of Fisheries, on Marine Department file, "Area [off Tapu] will soon become uneconomic and problem [of excessive dredging there] will automatically resolve."

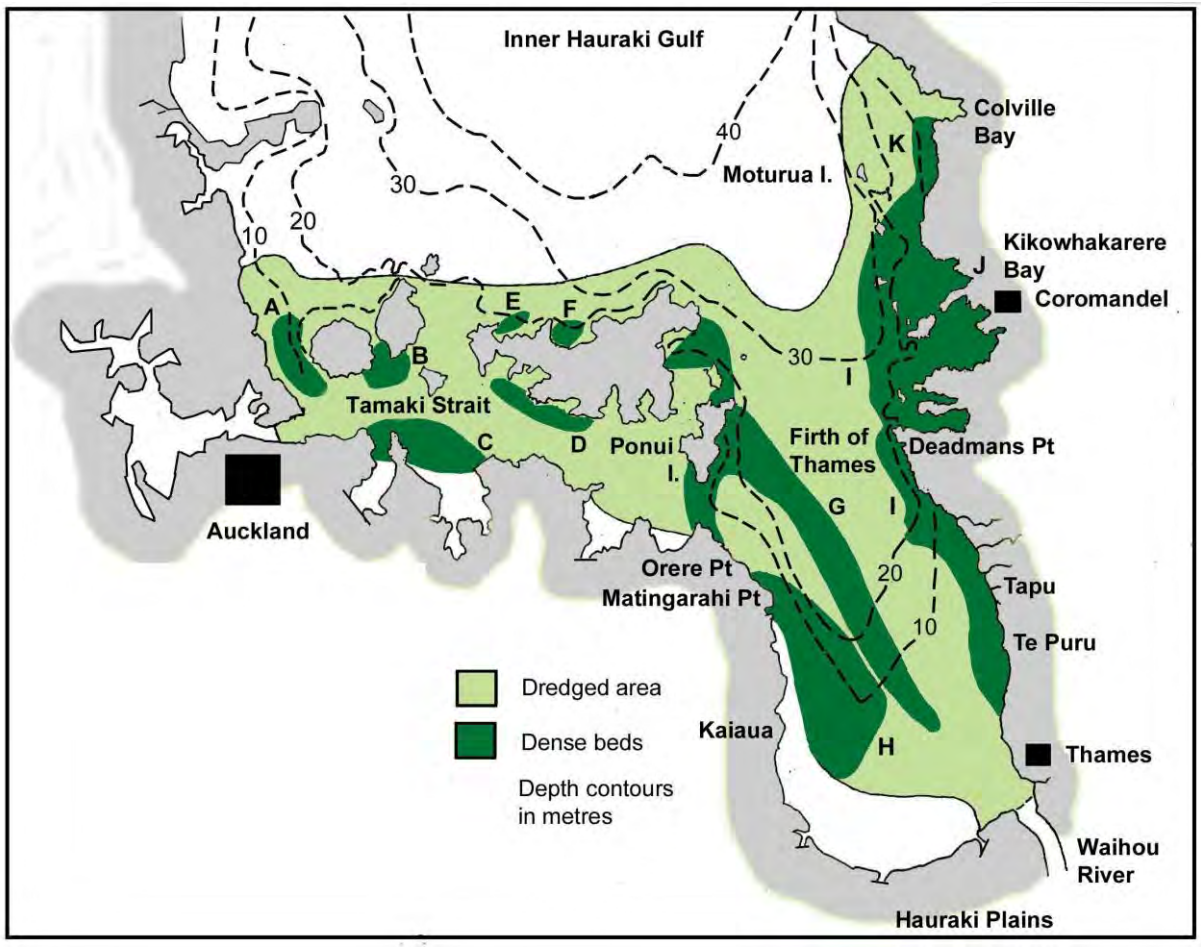

Figure 5: Map of the inner Hauraki Gulf and the Firth of Thames, showing the area worked by the green-lipped mussel dredge fishery and the position of the main mussel beds. Redrawn from Reid (1969), with depth contours added. The letters cross-refer to the beds listed in Table 1.

Despite the absence of quantitative data, it is apparent that more than local and temporary over-exploitation was occurring during this decade, and probably earlier. The clearest account is given by Reid (1969), who reported on the status of the fishery as in 1958. He did not survey the grounds (contrary to the title of his report), but undertook some inconclusive experiments on growth rates, briefly described the history of the fishery, the dredging gear used, and drew heavily on the experience of dredge fishermen to describe the condition of all the known beds, and the theories they put forward for the observed decline in mussel numbers on many of these. His work is summarised here in Figure 5 and Table 1.

Reid's report in the late 1950s revealed that although "mussels were still widespread and in places abundant in the Hauraki Gulf and Firth of Thames," there was clear evidence from exploratory dredging on once-productive beds that very serious declines had occurred in many areas, and that these beds were completely fished out. They were usually those beds which could be most easily located by using prominent landmarks.

Table 1. Notes on the main mussel beds, based mainly on anecdotal information supplied by fishers in 1958 as recorded by Reid (1969). Where possible, the names follow those in Reid's text and his Figure A. The dates when beds were worked are unfortunately not recorded. Quoted text is taken directly from Reid. For the location of the beds see Figure 5.

Bed Region	
A, Rangitoto Channel	Fairly extensive and well-populated beds. Worked briefly "shortly after commercial operations started," ceased when nearby rock oysters were found to be infected with *Salmonella*, but worked intermittently again in later years.
B, Motutapu	Islington Bay contained "good beds of limited area," but not "dredged for some time."
C, Beachlands	Moderate beds with small areas of higher abundance, lightly exploited in earlier years.
D, South Waiheke	As for Beachland beds.
E, Oneroa	No comments by Reid. Likely to be small beds lightly or briefly worked.
F, Onetangi	As for Oneroa.
G, Ponui-Thames	1. East and south of Ponui I. "Extensive beds ... worked sporadically for the last thirty years ... now showing signs of depletion." 2. Ponui towards Thames. "The main source of supply of large mussels for many years. [In 1958] the beds contain moderate to poor stocks of small mussels."
H, Southwest Firth	1. From Orere Pt to Kaiaua. An area of "extensive mussel beds [and] the main source of supply in [the mid-50s]." Moderate sized mussels. 2, Kaiaua to SW Firth. A shallow area of extensive beds, but the mussels were only ever moderate in density and size. Worked in previous decades because of its proximity to the landing port of Thames.
I, Eastern Firth And Coromandel	"At one time mussel beds varying in abundance extended along the whole of the Coromandel coastline from Te Puru to Colville Bay [with] the most abundantly stocked beds in the Hauraki Gulf area. Over the years these beds were the most extensively exploited and are now the most depleted." Several sub-regions are described by Reid, most with beds relatively close to the shore, and virtually all, in 1958, seriously fished out or "barren" and "uneconomical."
J, Kikowhakarere	One of the Coromandel series of bed complexes. The bay formerly yielded perhaps the highest catches of any beds, was heavily worked by Coromandel, Thames, and Auckland dredgers, and by 1956 was among the most depleted. When present, the mussels "were concentrated around the bay margins, and around the headlands and adjacent islands." Even the central bay, with a seafloor of mud and weed, contained moderate beds.
K, Colville Bay	"The mussel beds from Kikowhakarere Bay to Colville Bay carried only moderate stocks and were lightly dredged on occasions."

3.8 The 1960s – Final boom and bust

Landings rose from 2600 t in 1960 to almost 2800 t in 1961 (Figure 2), the highest landing on record. In subsequent years the landings dropped rapidly, despite increased searching time (Greenway 1969), through 1650 t in 1963, 850 t in 1964, and 100 t in 1966. The fishery became commercially uneconomic; full-time dredging ceased in 1967 (Greenway 1969), and landings reached zero in 1969.

Despite the clear warnings in Reid's 1958 study,[23] the Marine Department made little effort to bring the fishery under sustainable management, and its Reports on Fisheries simply recorded its decline

[23] Undertaken by the Marine Department and thus immediately available to its fishery managers, although not formally published until 1969.

and collapse following the year of peak landings.[24] This was at a time when New Zealand's fisheries as a whole were coming under intense scrutiny through a Parliamentary Enquiry (1961–62). Submissions from the mussel industry and the Department did point out that this fishery was in serious danger, and this was noted in the Report,[25] but it was overridden by the general conclusions of the Enquiry that the restrictive licensing of New Zealand's fisheries should be replaced with a more open-access registration system. Although mainly directed at encouraging the country's potentially large and undeveloped offshore finfish fisheries, stressed local fisheries were also caught within this relaxation of controls. In 1960 and 1961 three more or less full-time mussel dredgers operated in the Firth. This increased to four in 1962 and eight in 1963, although only two of the additional vessels worked full-time. The registration and entry to the fishery of these new vessels was allowed under the new, essentially open-access, management regime despite very strong reservations expressed by Auckland Fisheries Inspectors with direct knowledge of the mussel fishery (Chisholm 2005). It is clear that de-licensing did significantly increase dredging effort, in contrast to the unknown effect of the recorded rise in vessel numbers in the late 1950s. It was speculated much later that it was this increase from three to five full-time vessels that brought about the fishery's collapse (Chisholm 2005), but from the evidence collected in 1958 by Reid (1969) it seems more likely that it simply hastened it.

The Department did, however, acknowledge that the mussel dredge fishery was in serious trouble. More urgent studies were begun into investigating mussel biology (particularly reproduction, spatfall, and growth rates) e.g., Greenway (1972, 1975), McFarlane (1972), Hickman (1983, 1989, 1991), annual dredge surveys were carried out in the Firth of Thames or those parts of it which remained productive (Greenway 1969), and collaborative research into more practical aspects of aquaculture was started in conjunction with universities and private enterprise.

The first scientific dredge survey of the mussel fishery was conducted in 1961; the survey covered the entire Firth and extended north along each coast to Coromandel and just north of Ponui Island (Greenway 1969). Reasonable quantities of mussels were found only along the western Firth, from Ponui to Kaiaua, centred on Matingarahi Pt (see Figure 5), plus a small concentration associated with a bed of mud oysters *Ostrea lutaria* in the central Firth east of Kaiaua. Subsequent surveys through to the mid 1960s were restricted to the two areas of greatest abundance in 1961: east of Ponui Island, and off Matingarahi Point. In both areas mussel abundance dropped dramatically after 1964. The Ponui series (1962, 1963, 1965) yielded 5.0, 4.6, and 0.5 mussels per two-minute tow, and the Matingarahi series (1962, 1963, 1965, 1966) 26.9, 16.6, 1.5, and 0.6. This essentially matched the collapse in commercial landings from 1964 to 1965. Greenway (1969), in fact, noted that Matingarahi and Ponui were the last viable beds to be worked.

[24] In 1961, "...additional measures may perhaps be necessary to prevent over-exploitation." In 1962, "...additional restrictions may be necessary if depletion of the mussel beds by excessive dredging is to be avoided." In 1965, "Auckland mussel production declined to a record low level [...] Results [of surveys] indicate that in [the Firth] the population of mussels is at a low ebb." In 1967, "The [dredge] survey showed that the depleted condition of stocks, noted in 1965 and 1966, still pertained. The most likely explanation for lack of regeneration appears to be the absence of good settlement surfaces due to the extensive dredging of 1962–63."

[25] "These observations point to the conclusion that dredging on the present scale was having a very adverse effect on the beds and that once a bed is denuded recovery may be very slow. On the basis of present knowledge it seemed doubtful how much longer the industry could continue at its present level." W.J. Scott Committee Report, 1962.

Figure 6: Dredged mussels preserved in vinegar and packed in four-gallon cans for the domestic market, Coromandel Mussel Company, Auckland depot, early 1960s. Source: The Weekly News, 14 August 1963, courtesy Hocken Collections, Uare Taoka o Hakena, University of Otago.

The popularity of mussels remained strong in Auckland, as canned product as well as fresh in-shell mussels (Figure 6). This is reflected in their landed value, which remained at less than $1 per sack through the 1950s but approximately doubled between 1958 and 1960 (there was no comparable increase in wetfish values). The relationship between landings and value (Figure 7) shows this price rise occurring during the period of highest landings, presumably allowing the dredge fishery to remain profitable, although perhaps only marginally so, even as vessel catch-per-effort anecdotally declined. However, Chisholm (2005) provides a brief account of the rapid decline in catch rates in the mid 1960s as observed by a Fisheries Inspector aboard one of the main dredgers. In 1964 a day trip took about 200 sacks, in 1965 less than 100 sacks despite longer tows, and in 1966 between 20 and 40 sacks despite "a huge effort." Chisholm also commented that prices increased as catches (and, obviously, catch rates) declined. Greenway (1972) noted that in the final years of the fishery "boats spent more time away from the base, with considerable time spent in fruitless searching."

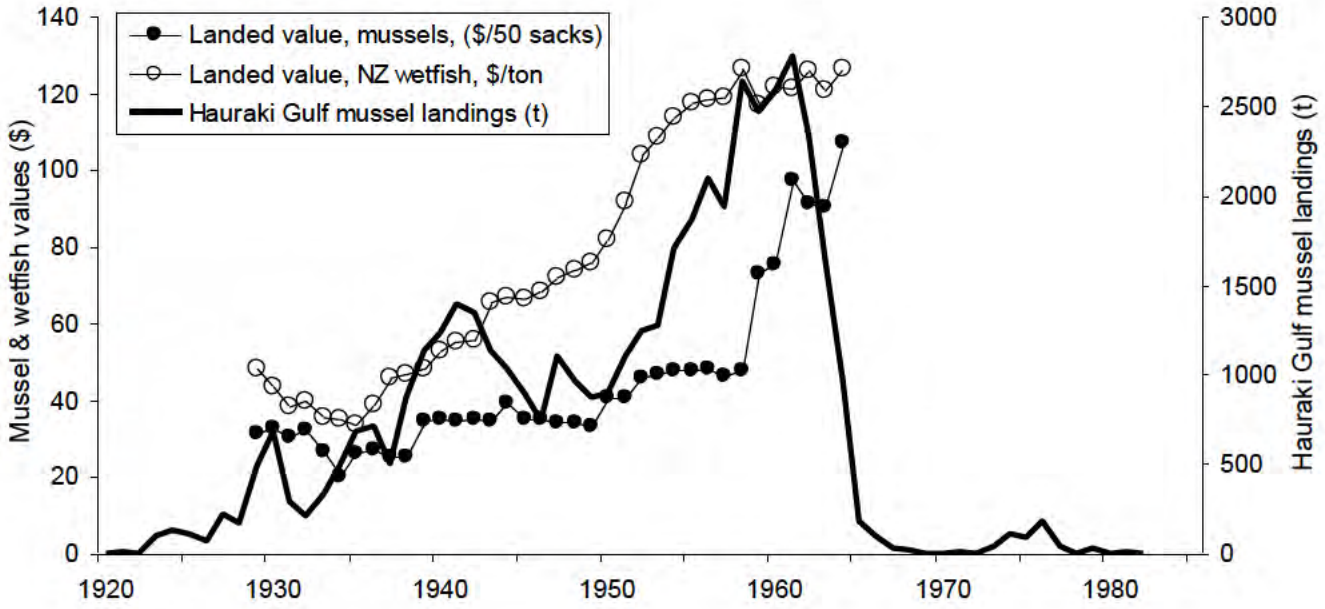

Figure 7: Landed per-sack value of green-lipped mussels, in relation to trends in the landed tonnage from the Hauraki Gulf. The landed per-ton value of New Zealand wetfish is also shown. Note: mussel values are given for "50 sacks" in order to obtain comparable figures.

The dwindling supplies from the Firth and inner Gulf beds were augmented by an increasing volume of mussels freighted north from Nelson. Small quantities of mussels were first landed at Nelson in 1960, taken as bycatch in the dredge fishery for scallops just developing in Golden Bay. This trade increased rapidly as mussels became a more popular seafood, and very quickly the seafloor mussel beds in Golden Bay, Tasman Bay, and the Marlborough Sounds were targeted, and some hand-picking from intertidal rocks took place. The vessels involved were small multi-purpose fishing boats, able to shift rapidly (seasonally) between trawling, line-fishing, trolling, and dredging. Landings from the Nelson area fluctuated between 1000 t and 2700 t between 1965 and 1974, before plummeting to commercial extinction in about 1980 in a similar manner to the Firth fishery (closure of some beds for the 1967 season had little effect). In sequence, the Firth of Thames and then the Tasman/Marlborough landings continued to supply the market up to 1980, mainly in the Auckland region, although the demand appears to have exceeded the supply (see following section). Failure of the Firth fishery also prompted development of small and variable dredge and hand-picking fisheries in some north-west coast harbours, notably Manukau and Kaipara (Appendix 2), which could directly supply the Auckland market. The popularity of mussels as seafood was also increasing outside the Auckland region. From 1965 to 1972 small landings were recorded from eastern Bay of Plenty harbours.

More importantly, mussel farming (Section 3.10, below) was in its infancy but showing considerable promise, and it seems likely that the mussel industry and the government (the Marine Department, and the Ministry of Agriculture & Fisheries from 1972) saw greater potential in the development of aquaculture than in resuscitating a still poorly understood wild fishery apparently doomed to collapse.

3.9 From 1967 to 1978 – Poaching for profit

For about a decade, from the late 1960s to the late 1970s, mussel poaching occurred on a relatively large scale in the Auckland region (Chisholm 2005). Most of this was centred on Orere Point at the western entrance to the Firth of Thames (see Figure 5), close to the beds worked in the final years of

the commercial fishery. Dredging had destroyed the mussel beds on the open seafloor, and hand-picking by commercial and recreational fishers had removed most large mussels from the intertidal area and accessible shallow reefs. The main concentrations remaining were on a reef at 25 m depth in the outer Firth midway between Ponui Island and Coromandel, and on some shallow reefs a short distance offshore in the northwest Firth and eastern Tamaki Strait, on seafloor too rough for dredging and beyond the reach of most recreational shellfish collectors. Despite the supply of mussels from Nelson and west coast harbours into legal markets, there was still enough demand for the shellfish for poaching gangs to make large profits by supplying those fish shops willing to risk selling illegal product, and − more importantly − by surreptitiously raffling bags of mussels in large hotel bars. Divers used scuba gear (illegal for mussel collecting at that time) to reach the beds, and put their mussels into sacks which were left underwater and retrieved when the risk of surveillance was considered low. Cars were used to transport the sacks to Auckland addresses. This activity quickly came to the attention of Fisheries Inspectors, who despite limited resources and numerous other duties were in due course able to identify, catch, and successfully prosecute the main offenders. Large fines eventually deterred the poachers, as did the loss of their markets in the 1980s when large hotel public bars were replaced by smaller taverns, and the supply of relatively cheap farmed mussels to retail outlets increased (Chisholm 2005). The quantity of poached mussels taken during this decade is unknown. In the late 1970s there was also some poaching of mussels from west coast harbours to supply the Auckland demand (Johnson 2004).

3.10 1965 – Mussel farming experiments begin

The development of mussel farming in New Zealand has been extensively described elsewhere (e.g., Jenkins 1979; Hickman 1989a, 1991; Dawber 2004) and lies outside the scope of the present account, but there is an association with the Firth fishery worth noting. Experimental cultivation of mussels in New Zealand was initiated by the company that added the last two dredge vessels to the fishery, and was situated in the north-western Firth not far from the last viable beds, and from the area subsequently heavily poached. It was an entrepreneurial company, initially supplying the traditional mussel markets but soon experimenting with extracting pharmaceutical products from mussel flesh, particularly for treating arthritic-related ailments (McFarlane 1972, 1975). A small pontoon raft with hanging ropes was anchored off Ponui Island, but numerous problems were encountered. Spatfall was unreliable, spat retention on different materials proved problematic, too much mud settled on ropes and spat in the shallow, sheltered, and turbid Firth waters, there were legal uncertainties in using coastal waters for "farming," and opposition from other maritime users (yachtsmen, fishermen, etc.) concerned at losing navigational freedom and the future prospect of visual pollution of the coasts. The company persevered with experiments through the late 1960s and 1970s, supported indirectly by the Marine Department and the Fishing Industry Board. A significant drop in demand for the medicinal product was a further setback, and demonstrated the risk of depending on a single market outlet.[26] Other small-scale and experimental farming operations were started in the Firth in the 1970s; the first farmed mussels being offered for sale in Auckland in 1978 (Dawber 2004), with steadier quantities available from about 1980, in competition with dredged mussels from Kaipara Harbour. By this time, however, the main centre of mussel farming research and development was in the Marlborough Sounds, which has remained the principal mussel aquaculture region to date.

In the mid 1980s, renewed and more successful farming ventures were developed near Coromandel, with the prediction that an annual yield of 10 000 t was possible (Hickman 1989a). No formal record has been kept of the increase in farmed production from the Firth through the 1990s and early 2000s, aquaculture becoming an industry rather than a government-controlled fishery, but in 2004 production was 12 000 t, increasing to 21 000 t in 2006 (N.Z. Mussel Industry Council website), the tonnage mainly limited by market demand.

[26] Subsequent clinical trials on the effectiveness of mussel extracts have proved inconclusive (Cobb & Ernst 2006).

3.11 Possible causes for the collapse of the fishery

A number of theories have been proposed for the fishery's collapse, and also for the failure of the mussel beds to recover even after several decades of no fishing. The earliest comments on the status of the fishery deal only with the localised or (later) the complete destruction of the beds; more recent hypotheses also attempt to explain the lack of recovery.

Crushing: Incidental mortality from crushing (by fishing trawls) was briefly discussed in the report of the 1919 Auckland Fisheries Commission, but considered unlikely. Damage caused by mussel dredges, i.e., mussels killed but not caught, was claimed at intervals over subsequent decades but never substantiated. Determining the extent of damage would have been challenging; the very turbid Firth water would make direct observation, e.g., by divers difficult and dangerous and appears not to have been considered. Greenway (1969) noted that "less than 1% of dredged mussels are damaged by the dredge," but his comment presumably refers to mussels caught and retained by the dredge. His surveys did find patches of dead mussels where high-density beds had existed, and he suggested that these may have resulted from smothering by mud and shell disturbance by dredging. Thus, although there may have been little direct crushing damage to the caught mussels, there could have been dredging-related mortality to those left on the seafloor.

Siltation: Around the turn of the twentieth century significant changes occurred across the Hauraki Plains, the main catchment for rivers draining into the Firth of Thames (Tye 1974; Park 1995, 2001; Hatvany 2008). Extensive "forest clearance" began about 1875 and continued through the first decade of the twentieth century, the dominant tree of the swamp forest (kahikatea) being converted to butter-boxes. Drainage of the extensive swamp and wetlands began in 1890, and then from about 1910 through the 1920s this greatly increased as a consequence of a government-sponsored scheme to create farmland for dairying (the Hauraki Plains Swamp Drainage Act 1908). Watercourses and rivers were canalised to increase the rate of flow. A high sediment load undoubtedly entered the Firth during these decades. This preceded the Firth mussel fishery, but flood events over the cleared land in subsequent decades would also have brought pulses of sediment into at least the southernmost Firth. Possible smothering of beds by silt was raised as an unresolved issue in 1929. The Waihou and Ohinemuri Rivers had been straightened to reduce flooding over the low-lying Hauraki Plains, and it was believed the faster flow of the Waihou was taking a greater sediment load out through its estuary into the Firth[27]. In 1944 and 1945, siltation resulting from further forest clearance was suspected by one of the long-standing fishers of affecting mussel beds lying most directly in the path of the Waihou outflow through the central and eastern Firth, where "once-prolific beds" had become areas of "dead shell and poor-quality mussels."[28] In 1945 it was also speculated that cyanide from gold-workings might have entered the Firth from surrounding catchments.[29] Silt affects suspension feeders such as mussels in several ways: direct and complete burial of beds, clogging of feeding structures, interfering with food particle selection and requiring energy to reject inorganic material, and coating the spat settlement surfaces on the seafloor (Thrush et al. 2004).

Excessive fishing pressure: In 1938 one of the mussel processing factory owners claimed that the rate of exploitation was too high and that the "mussel beds … will be totally depleted within the next 10 years."[30] He recommended a closed season. The Marine Department was not convinced, although Fisheries Inspectors did concede that there was no evidence either for or against this claim. Their view was that there was only localised depletion, that other areas of the Firth and Gulf needed to be

[27] Annotated correspondence on Marine Department file M 1 2/12/448 part 1, Firth of Thames – siltation data – as to the effect on the fisheries therein, 1929, National Archives, Wellington. A.E. Hefford (Chief Inspector of Fisheries and Director of Fisheries Research) acknowledged a lack of knowledge on the extent of siltation and the desirability of determining its effect on bottom fauna, but suggested that the quality of silt rather than its quantity could be more important. This may reflect a concern that mine wastes were entering the Firth.
[28] Note by E. Gilliver [Inspector of Fisheries, Coromandel] 9 August 1945, M 1 2/12/328, part 2, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1942–1949, National Archives, Wellington,
[29] Notes on mussel dredging by A.E. Hefford, 7 March 1945, M 1 2/12/328, part 2, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1942–1949, National Archives, Wellington..
[30] Letter by C.G. Macindoe to Minister of Marine, 8 July 1938, M 1 2/12/328, part 1, Mussels – Coromandel and Hauraki Gulf – leasing of areas, 1924–1938, National Archives, Wellington.

explored, and that some known beds had dense mussel aggregations that appeared overcrowded and would benefit from being worked. In the 1940s and 1950s there were further generalised claims of over-fishing, but no management action was taken. It is now recognised that shellfisheries can suffer stock depletion and population collapse from recruitment overfishing – the inability of an adult stock to replenish itself. Despite a high reproductive potential, if the adult biomass is significantly reduced and aggregations (colonies or beds) are dispersed the proportion of successfully fertilised eggs will fall, reducing the number of larvae that reach and settle on suitable surfaces. It has been a contributing factor, for example, in declines in The Wash mussel fishery, U.K. (Dare et al. 2004), in the California abalone fishery (Rogers-Bennett et al. 2004), and (in association with stock or growth overfishing) in the Chesapeake Bay oyster fishery (Rothschild et al. 1994). It may well have been a factor in the Firth of Thames fishery, but is unlikely to have been the major one.

Loss of settlement surfaces: Observations during the first scientific survey of the Firth's mussel beds in 1961 suggested that mussels were preferentially attached to other live mussels or to recently-dead shells, rather than to old shells (Scott Report 1963, presumably based on Marine Department evidence). (This observation appears to pre-date research findings from several benthic invertebrates showing that chemical and tactile cues result in preferential larval settlement on or near conspecific live adults (e.g., Rodríguez et al. 1993, Nielsen & Franz 1995), including mussels (Gribben & Wright 2006).) The Scott Report concluded that "dredging on the present scale was having a very adverse effect on the beds, and that once a bed was denuded recovery may be very slow," and warned that "it seemed doubtful how much longer the industry could continue at its present level." The published account of the 1960s surveys (Greenway 1969) was less specific, stating only that dredging left "an unstable muddy substrate unsuitable for attachment," that natural bed regeneration was unlikely, and recommended only that mussel shells (or preferably heavier shells such as oysters) be returned to the water as culch. Subsequent accounts of the mussel fishery have accepted the explanation that loss of suitable settlement surfaces was the main cause for its failure. However, if spat settlement is influenced by the presence of live mussels, the return of dead mussel (or oyster) shell might have had limited success.

In summary, mussel beds in the Firth of Thames and adjoining shallow Hauraki Gulf areas were "over-fished," in the sense that the exploitation rate was simply too high. The principal cause, as earlier accounts have concluded, is almost certainly the removal of the beds of live mussels on to which juvenile mussels recruited. Compounding factors include the probability that a diminishing adult population increased the risk of recruitment failure, there may have been a lessening of any cues encouraging larvae to settle near adults, and a more silty − perhaps more mobile − seafloor with a sparser benthic community may have reduced the areas suitable for primary larval settlement.

4.0 DISCUSSION

At first glance, this fishery shows the pattern of so many others − for fish, crustaceans, and shellfish − that were developed in the early years of the twentieth century in New Zealand (e.g., Gibbs 2008), a pattern apparent in almost all world fisheries. Typically there is a hesitant start, steady development as gear improves and good markets develop for the product, a belief that the resource − if not inexhaustible − is widespread and abundant, and that declines in catch rates are localised problems which can be resolved by searching further afield. As in so many fisheries, a harvest was taken and renewal left to nature. There was little management action, limited to closing some of the earliest and consequently most heavily depleted beds close to the landing port of Coromandel. In fact, as late as the early to mid 1950s government fisheries managers (the Marine Department) believed that yields could be increased by fishing the densest ("over-populated") beds harder, to encourage growth and improve mussel condition. However, the comment that "There were no attempts to manage the fishery …" (Hickman 1991) is not entirely true. There was an assumption by the government managers that New Zealand's restrictive licensing regime (applying to all fisheries) would be an adequate safeguard. It constrained the number of dredging vessels to less than six, of which half or less worked full-time and were run by only two companies. Mussel dredging in the Firth appeared to be a small self-

regulating fishery based on a productive resource. Landings increased steadily over time, although catch rates were not monitored. Only when the first scientific investigations were carried out in 1958 (Reid 1969) and in the 1960s (Greenway 1969) was it fully appreciated that serial depletion of mussel beds was occurring, and that although reasonable − though unpredictable − quantities of spat were still being produced there were diminishing areas of suitable substrate (existing mussel beds) on which settlement could occur. Although "productive" in terms of individual growth rate, the mussel population was being increasingly restricted by a steady loss of its habitat. Hickman (1991) aptly summarised the problem thus: "the dredging process was, by its very nature, destructive of the beds, removing at the same time the adult stock and the potential settlement surfaces for the spat." When licensing was replaced by essentially open-access vessel registration in 1963 the potential impact on small fisheries such as this appears to have been overlooked. However, the sudden increase in dredging effort that resulted is more likely to have simply hastened the fishery's collapse, rather than caused it. Heavy sediment loads entering the Firth may have affected some beds, but there is no direct evidence for this.

Ironically, part of the problem and a partial solution was foreseen by some of those involved in the mussel industry as early as the 1920s. Dredgers who chose to "farm" a mussel bed by taking only a proportion of the stock, leaving the remainder to regenerate, were thwarted by others who dredged out the rest. Appeals to lease areas of harbour and shallow coastal seafloor were made. This became possible in 1930 by linking mussels to fisheries legislation covering artificial ("farmed") rock oyster beds, but no applications for mussel leases were received. Had such ventures proceeded, it is possible that the necessity of retaining suitable substrates (e.g., part of the natural mussel bed) would have been recognised much earlier, when lightly-fished beds recovered and heavily-fished beds did not. Experiments to replicate good substrates would have been made, and some form of mussel farming would have commenced decades earlier than it did. Or at the very least, a stronger and more precautionary management regime would have been imposed on the dredge fishery.

There is no clear explanation for the failure of most of the once-prolific mussel beds in the Firth and inner Gulf to recover during the four decades following cessation of the dredge fishery. A survey of soft-sediment seafloor communities in the Firth and inner Gulf was undertaken in 2002 using echo-sounding and side-scan sonar, ground-truthed by grab-sampling and a sled-mounted video system. It did not locate mussel beds in areas where they had once existed (Morrison et al. 2002, 2003), and only single mussels or small clumps were seen. Mussels are short-lived, maturing in their first year, and in appropriate conditions are highly productive. Even if larval production and spat settlement is somewhat erratic (as the early farming ventures discovered) it is surprising that the remnants of the population were unable to re-form beds on small patches of firm seafloor and then expand, mussels growing rapidly upon mussels. Small concentrations of mussels are in fact forming underneath the mussel farms which have operated in the Firth for a decade or two, presumably based on individuals which have dropped off the vertically-strung ropes, and mussels do survive in the sediment-laden waters of the shallow Firth (McLeod 2009, and pers. comm.) but have not yet created real beds.

It should perhaps be noted here that one hypothesis for the initial formation of the Firth beds, and perhaps others in the Gulf, is that a major episode of bush clearance created areas of woody detritus on the seafloor upon which a critical mass of mussels might have settled (Greenway 1969). Subsequent land clearance and pasture development in the catchments − particularly the drainage of wetlands − may have only produced high sediment loadings in the riverine inputs to the Firth, with little or no substrate material. There may not yet be a sufficiently large area of firm substrate, either of assorted debris or living and dead mussel shells, to support this critical spatial area of mussels. From the perspective of mussel production the issue is academic, as a future dredge fishery is unlikely to be competitive with aquaculture in both quantity and quality of product. However, some understanding of the factors necessary for bed creation and survival would be beneficial to interpreting mussel population dynamics. More importantly, the loss of extensive mussel beds has significantly altered the benthic ecosystem, removing hard surfaces upon which many invertebrate species settled, thus directly and indirectly impoverishing the communities preyed upon by several ecologically and economically important finfish species. It will also have changed bentho-pelagic coupling, i.e., natural

mussel beds will no longer be filtering plankton from Firth of Thames water, although this will be locally offset by the establishment of mussel farms. Soft-bottom benthos is known to alter zooplankton community composition (e.g., Kimmerer et al. 1994).

There are some parallels with the mussel (*Mytilus edulis*) fishery in The Wash, England, described by Dare et al. (2004). This was an important but variable fishery for over a century, commencing − in association with a cockle fishery − in the early 1900s. From 1970 to 1990 its landings fluctuated between 1500 and 9000 tonnes, dropping to zero in 1993. Subsequent recovery was extremely slow, and had to be aided by transplanting seed mussels from outside the area (Roberts & Jones 2009). The collapse was attributed to over-fishing, with the exploitation rate increasing from about 25% prior to 1970 to 50% or more after 1982. Suggested possible factors which limited the ability of the beds to recover included siltation, low and variable recruitment, destruction of juveniles during adult harvesting, and the much smaller size of surviving beds together with damage to their physical structure, reducing the area of protected firm substrate where spat could survive.

After decades of successful exploitation the Firth dredge fishery failed, essentially because too little was known of mussel ecology. Although this deficiency was realised at the time, no management action was taken as the exploitation rate steadily increased. Marine farming has now replaced almost all commercial wild mussel fisheries in New Zealand, developed by practical trial and error, and supported by appropriate research (Dawber 2004).

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9.0 APPENDICES

Appendix 1: Recorded landings of green-lipped mussel, *Perna canaliculus*, at the Hauraki Gulf ports of Auckland, Thames, and Coromandel. Values in sacks to 1973 mainly as originally reported in Annual Reports on Fisheries (some data are derived from unpublished reports in National Archives). Subsequent values in tonnes from King (1985) converted to tonnes on the basis that 1 sack = 150 lbs (see text). Dredge vessel numbers are from the same sources. Some early high values may have resulted from the use of smaller sacks. Port landings in the original data (but not listed here) do not represent regional subtotals; before 1946 Coromandel was variously combined with Thames or Auckland in published reports, and dredge vessels landed into the ports where their owners' factories were situated, not necessarily the closest port. Most landings are from the dredge fishery, with a small quantity from hand-picking. A dash (–) represents no data. NA = not available; dredge vessel numbers are listed by King (1985) but they are predominantly scallop dredgers.

	Landings		No. dredge vessels				Landings		No. dredge vessels		
	Sacks	Tonnes	Full-time	Part-time	Total		Sacks	Tonnes	Full-time	Part-time	Total
1923	1 454	99	–	–	–	1953	18 781	1 278	–	–	3
1924	1 900	129	–	–	–	1954	25 069	1 706	–	–	4
1925	1 600	109	–	–	–	1955	27 358	1 861	–	–	6
1926	1 000	68	–	–	–	1956	30 849	2 099	–	–	6
1927	3 190	217	–	–	–	1957	28 389	1 932	–	–	9
1928	2 500	170	–	–	–	1958	38 713	2 634	–	–	13
1929	7 242	493	–	–	–	1959	36 173	2 466	–	–	17
1930	10 063	685	–	–	–	1960	37 865	2 581	–	–	3
1931	4 242	289	–	–	–	1961	40 910	2 784	–	–	3
1932	3 093	210	–	–	–	1962	34 420	2 342	–	–	4
1933	4 888	333	3	1	4	1963	24 399	1 660	–	–	8
1934	7 152	487	2	2	4	1964	14 229	968	–	–	5
1935	10 099	687	4	2	6	1965	2 724	185	–	–	4
1936	10 415	709	3	1	4	1966	1 480	101	–	–	5
1937	7 411	504	3	1	4	1967	384	26	–	–	4
1938	12 869	876	3	0	3	1968	301	20	–	–	11
1939	16 631	1 132	4	2	6	1969	0	0	–	–	3
1940	18 088	1 231	2	2	4	1970	0	0	–	–	1
1941	20 449	1 391	2	3	5	1971	219	15	–	–	2
1942	19 726	1 342	3	1	4	1972	1	0	–	–	4
1943	16 720	1 138	2	2	4	1973	525	36	–	–	1
1944	15 227	1 036	3	1	4	1974	1 559	106	–	–	3
1945	13 156	895	3	0	3	1975	1 397	95	–	–	NA
1946	10 928	744	2	0	2	1976	2 677	182	–	–	NA
1947	16 261	1 106	2	1	3	1977	544	37	–	–	NA
1948	14 224	968	1	2	3	1978	0	0	–	–	NA
1949	12 806	871	2	1	3	1979	397	27	–	–	NA
1950	13 168	896	4	0	4	1980	15	1	–	–	NA
1951	16 163	1 100	–	–	4	1981	176	12	–	–	NA
1952	18 343	1 248	–	–	5	1982	59	4	–	–	NA

Appendix 2: Recorded landings in sacks from natural populations of green-lipped mussel, *Perna canaliculus*, from regions outside the Hauraki Gulf. Values in sacks to 1973 as originally reported in Annual Reports on Fisheries; values from 1974 (King 1985) are converted to sacks from reported tonnes (1 sack = 150 lbs). Most landings are from dredge fisheries, with small quantities from hand-picking. West Northland/Auckland landings are mainly from Kaipara and Manukau Harbours; East Northland are from Mangonui and Russell; Bay of Plenty from Mercury Bay, Tauranga, and Whakatane; East coast North Island from Gisborne and Napier, Tasman/Malborough from Nelson, Golden Bay, Picton, Pelorus, and Blenheim; Central and southern South Island from Kaikoura, Lytttelton, and Bluff.

Year	West Northland / Auckland	East Northland	Bay of Plenty	East coast North I.	Tasman / Marlborough	Central and southern South I.	Year	West Northland / Auckland	East Northland	Bay of Plenty	East coast North I.	Tasman / Marlborough	Central and southern South I.
1921	0	200	0	0	0	0	1952	0	0	98	23	0	0
1922	0	0	0	0	0	0	1953	0	0	78	480	21	0
1923	0	0	0	0	0	0	1954	2	0	491	625	0	0
1924	0	0	0	0	0	0	1955	5	0	230	29	0	0
1925	0	0	0	0	0	0	1956	0	0	0	25	0	0
1926	0	800	0	480	0	0	1957	0	0	0	22	3	0
1927	0	0	0	625	0	0	1958	0	0	0	18	0	0
1928	0	0	0	520	0	0	1959	0	66	0	8	0	0
1929	0	0	0	0	0	0	1960	0	72	0	5	40	0
1930	0	0	0	150	0	0	1961	0	0	0	10	56	0
1931	0	0	0	0	0	0	1962	87	0	0	23	180	0
1932	0	0	0	0	0	0	1963	0	0	21	7	1 082	0
1933	0	0	0	0	0	0	1964	0	0	0	46	10 835	0
1934	0	0	0	0	0	0	1965	0	0	0	40	28 947	0
1935	0	0	230	0	0	0	1966	9	0	0	35	29 811	0
1936	0	0	0	0	0	0	1967	375	0	0	58	22 025	0
1937	0	0	0	0	0	0	1968	1 232	32	186	11	28 258	0
1938	0	0	0	0	0	0	1969	2 188	0	2 039	0	16 819	3
1939	0	0	0	0	0	0	1970	1 073	106	487	44	15 723	3084
1940	0	0	0	0	0	0	1971	0	610	100	33	20 492	1907
1941	0	0	0	0	0	0	1972	4 484	32	98	111	40 149	663
1942	0	0	0	0	0	0	1973	10 502	3	0	61	35 392	53
1943	0	0	21	0	0	0	1974	13 515	88	0	29	15 780	456
1944	0	0	0	0	0	0	1975	9 853	74	0	74	12 044	15
1945	0	0	0	0	0	0	1976	3 324	162	0	29	26 824	44
1946	0	0	0	4	0	0	1977	897	59	0	147	7 853	59
1947	0	0	0	0	0	0	1978	6 280	0	44	235	3 750	44
1948	0	0	186	2	0	0	1979	12 383	15	0	868	2 882	29
1949	0	0	2 039	8	0	0	1980	20 589	29	0	1 118	1 103	132
1950	0	0	487	17	0	0	1981	19 486	29	0	176	191	29
1951	0	0	100	16	0	0	1982	12 206	29	0	132	15	15