DREDGE OYSTER (OYU 5)-Foveaux Strait

(*Ostrea chilensis*)

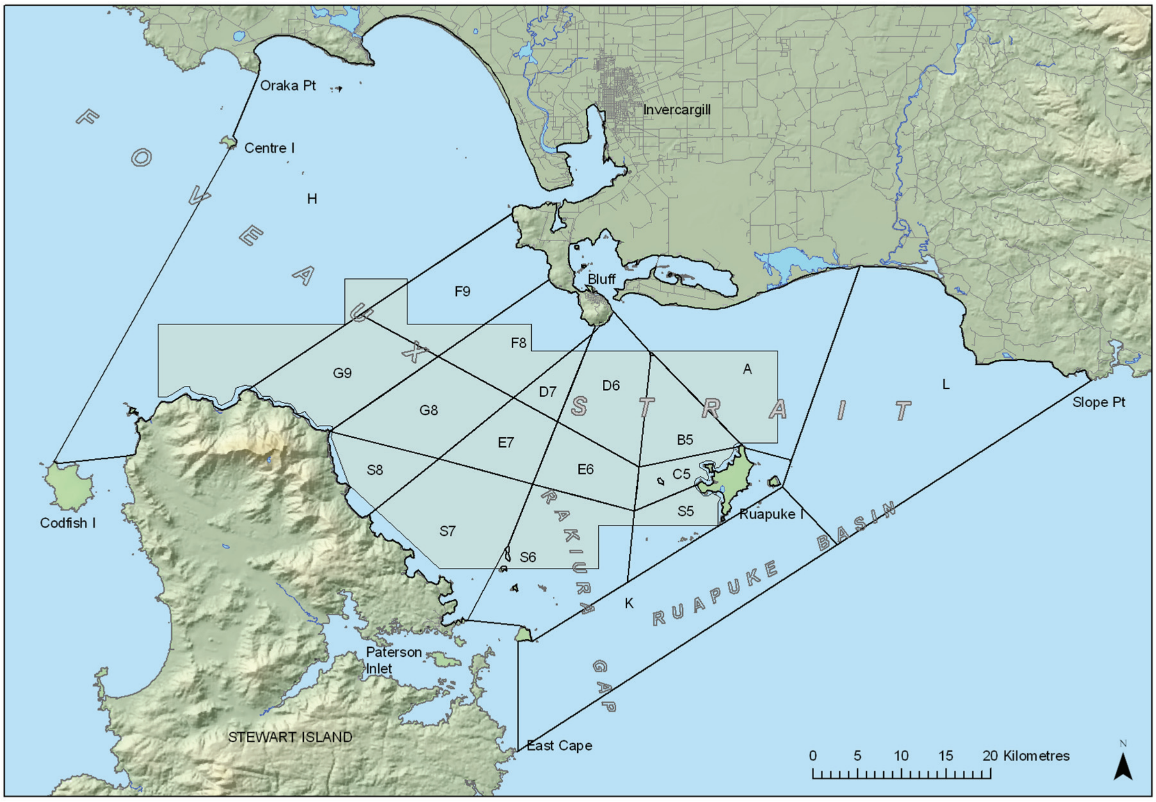

Figure 1: Foveaux Strait (OYU 5) stock boundary and outer boundary of the 1999 dredge survey area encompassing almost all the commercial fishery.

1. FISHERY SUMMARY

1.1 Commercial fishery

The Foveaux Strait dredge oyster fishery has been fished for over 140 years. From the late 1880s to 1962 the fishery was managed by limiting the number of vessels licensed to fish. During this period vessel numbers varied between 5 and 12. The fishery was de-licensed in 1962 and boat numbers increased to 30 by 1969. Boundaries of statistical areas for recording catch and effort were established in 1960 and the outer boundary of the licensed oyster fishery in 1979. The western fishery boundary in Foveaux Strait is a line from Oraka Point to Centre Island to Black Rock Point (Codfish Island) to North Head (Stewart Island). The eastern boundary is from Slope Point, south to East Cape (Stewart Island). The OYU 5 stock boundary and statistical reporting areas are shown in Figure 1.

Catch limits were introduced in 1963–69 and from 1970 vessel numbers were also limited to 23 by regulation. The catch limits were evenly divided between the 23 vessels. In 1979 the oyster fishery was declared a licensed fishery for the 23 vessels, closing a loophole that allowed vessels to fish outside the designated fishery area. Before 1992, landings and catch limits in this fishery were recorded in sacks. Sacks contained an average of 774 oysters and weighed 79 kg. Catch and effort has been traditionally recorded in sacks per hour dredged. Total landings of oysters between the 1880s and 1962 ranged between 15 and 77 million oysters. Reported landings for the period 1907–1962 are shown in Table 1. Catch limits and total landings for 1963–92 are shown in Table 2. Figure 2 depicts the per-stock catch composition, and the historical landings and TACC for the OYU5 fishery.

In 1986 a *Bonamia exitiosa* epizootic caused major mortality in the oyster population and the fishery was closed half way through the season to minimise disturbance to oysters. Management of the fishery was modified in response to the continuing mortality from *B. exitiosa*. In 1987, the infected area was closed to dredging to reduce disturbance (so as not to exacerbate infection) and the catch limit reduced in proportion to the population of the closed area (Table 2). In 1988 the restriction on fishing in infected areas was seen as inappropriate in the light of new evidence on how the disease was affected by disturbance and the catch limit was increased. In 1989 the catch limit was increased to the pre- 1986 level, with the proviso that it would be modified if catch and effort data, and the distribution of fishing showed that mortality had reduced the population further (through this period, catch and effort data provided the only information on abundance of oysters in the fishery). *B. exitiosa* infection and mortality continued to spread through Foveaux Strait and by 1990 mortality in the area first infected had reduced oyster density below a level that could be fished economically. The quota remained at 89 million oysters for the 1990 season. However, four weeks of fishing showed that mortality from *B. exitiosa* had become widespread and reduced the oyster population over much of Foveaux Strait. The quota was reduced to 36 million oysters. In 1991 an additional 14 million oysters were dredged from a strip in central Foveaux Strait to reduce the density of oysters with the aim of containing infection by *B. exitiosa* to the west. This strategy failed and infection and mortality continued to spread east. The devastated beds in central Foveaux Strait were closed in 1992 and fishing confined to the outer beds. The catch rate was the lowest in the recent history of the fishery and fishers caught less than a third of the catch available. In 1993, Foveaux Strait was closed to commercial fishing to allow the population to recover. Although *B. exitiosa* infection was widespread in March 1995, prevalence (4.5%) and intensity of infection was low, considered unlikely to be a factor. Monitoring the status of infection ceased in 1995. No heightened mortality was observed in the fishery between 1995 and 2000.

Another *B. exitiosa* epizootic was confirmed in March 2000. It was first identified in the same area as the 1980s epizootic where oysters had rebuild to high densities, and proceeded to spread throughout Foveaux Strait in a similar pattern and rate. By 2002, mortality from *B. exitiosa* had reduced the oyster population to about 40–65% of the 2001 size. Infection from *B. exitiosa* has continued to cause mortality since them, albeit at a lower levels of around 3–6%.

Three years after the closure, the population had rebuilt sufficiently for the Minister of Fisheries to reopen the fishery in 1996 with a catch limit of 14.95 million oysters. This catch limit was converted to a catch quota of 1475 t using a conversion factor of 801 oysters per 79 kg sack based on Bluff Oyster Enhancement Company data. The mean number of oysters per sack landed in 1996 was fewer than 801 so that the quota specified by weight was filled before 14.95 million oysters were landed. The number of sacks landed as well as the number of oysters they contained was tabulated from the 1996 Licensed Fish Receivers Reports (LFLR) data and a new conversion factor of 774 oysters per 79 kg sack estimated. Using this conversion factor, the catch quota for 1997–2001 was 1525 t. From 1996, catches were recorded as numbers of oysters, catch limits and total landings for 1996–2008 are shown in Table 3.

Between 1992 and 2000 the Bluff Oyster Enhancement Company Ltd was granted a special permit to catch oysters during the breeding season as part of their study of the viability of enhancing the oyster population, using spat settled on oyster shell. Permit allocations and reported landings are shown in Table 4. No special permit was issued in 1998.

In April 1997, individual quotas were granted and quota holders permitted to fish their entire quota on one vessel. At the same time, the Crown purchased 20% of the available quota from quota holders and transferred it to the Waitangi Fisheries Commission. The oyster fishery entered the Quota Management System in 1998. The number of vessels in the fishery has dropped from 23 in 1996, to 15 in 1997, and to 11 in 2006 and has remained the same since.

The commercial fishing year for oysters is 1 October to 30 September, but as oysters have been traditionally harvested over a six-month season, 1 March to 31 August (Southland Commercial Fishing Regulations), fishery data is reported by calendar year. When the fishery was reopened in 1996, the oyster season started between mid March and early June to avoid disturbing oysters after spawning and reduce the risk of infection by *B. exitiosa*. The oyster season continued to finish on 31 August although many vessels have filled the quota before then. In 2007, the fishery returned to a 1 March start to the oyster season.

Oysters have been commercially harvested from Foveaux Strait since the 1860s, and since the 1870s by dredge. Currently vessels tow two 460–530 kg, double bit, steel dredges on steel warps. Each dredge is towed off its own derrick, both on the vessel's port side. The dredges are towed along an elliptical track. Once the dredges are shot the vessel drifts down tide under minimal power turning in to the tide to haul the dredge. The dredge contents are emptied on to culching benches and the oysters sorted and sized by hand. Small oysters and bycatch are returned to the sea. Oysters are landed daily, live in the shell.

Table 1: Reported landings of Foveaux Strait oysters 1907–1962 (millions of oysters; sacks converted to numbers assuming a conversion rate of 774 oysters per sack for the years 1907–1992). (Data summarised by Dunn, 2005 from 1907–1962 from Marine Department Annual Reports).

Year	Catch	Year	Catch	Year	Catch	Year	Catch	Year	Catch
1907	18.83	1919	16.56	1931	28.28	1943	56.59	1955	60.84
1908	17.34	1920	20.67	1932	29.01	1944	49.50	1956	58.63
1909	19.19	1921	19.01	1933	32.64	1945	58.85	1957	60.14
1910	18.20	1922	21.11	1934	40.44	1946	69.16	1958	64.44
1911	18.90	1923	22.28	1935	38.48	1947	63.09	1959	77.00
1912	19.00	1924	18.42	1936	49.08	1948	73.10	1960	96.85
1913	26.26	1925	20.01	1937	51.38	1949	75.34	1961	84.30
1914	19.15	1926	21.54	1938	52.05	1950	58.09	1962	53.42
1915	25.42	1927	16.26	1939	58.16	1951	70.15		
1916	22.61	1928	30.03	1940	51.08	1952	72.51		
1917	17.20	1929	30.44	1941	57.86	1953	55.44		
1918	19.36	1930	33.11	1942	56.87	1954	51.29		

Table 2: Reported landings and catch limits for the Foveaux Strait dredge oyster fishery from 1963–92 (millions of oysters; sacks converted to numbers assuming a conversion rate of 774 oysters per sack). Catch rate shown in sacks per hour.

Year	Reported landings		Catch limit	Catch rate	Year	Reported Landings		Catch limit	Catch rate
1963	58		132	6.0	1978	96	2	89	17.1
1964	73		132	6.8	1979	88		89	16.6
1965	95		132	7.9	1980	88		89	15.2
1966	124		132	10.6	1981	89		89	13.4
1967	127		132	9.3	1982	88		89	13.2
1968	114		121	7.7	1983	89		89	12.3
1969	51		94	6.5	1984	89		89	13.8
1970	88		89	7.3	1985	82		89	12.1
1971	89		85	6.9	1986	60	3	89	10.5
1972	77		85	6.7	1987	48	4	50	10.9
1973	97	1	85	10.0	1988	68		71	10.0
1974	92	1	85	11.5	1989	66		89	10.7
1975	89		89	11.9	1990	36		36	6.4
1976	89		89	13.4	1991	42	5	36	5.8
1977	92	2	89	15.9	1992	5	6	14	3.4

1 Landings include catch given as incentive to explore 'un-fished' areas.
2 Landings include catch given as an incentive to fish Area A.
3 Season closed early after diagnosis of *B. exitiosa* infection confirmed.
4 Catch limit reduced by the proportion of the fishery area with oysters infected by *B. exitiosa* and closed.
5 Landings include catch given as an incentive to fish a 'firebreak' to stop the spread of *B. exitiosa*.
6 Fishing only permitted in outer areas of fishery.

Table 3: Reported landings and catch limit for the Foveaux Strait dredge oyster fishery from 1996–2008. Landings and catch limits reported in numbers (millions) of oysters. Catch rate converted to sacks per hour (774 oysters per sack) to compare with earlier data. Catch rate does not include oysters taken by crew as recreational catch. Reported catch rate based on number of sacks landed in CELR data and revised catch rate based on numbers of oysters landed and converted to sacks (774 oysters per sack). The numbers of oysters per sack can vary considerably depending on the sizes of oysters and epifauna attached.

Year	Reported landings	Catch limit	Reported catch rate	Revised catch rate
1996	13.41	14.95	5.9	5.8
1997	14.82	14.95	7 0	7.0
1998	14.85	14.95	8.3	6.7
1999	14.94	14.95	7.5	6.8
2000	14.43	14.95	7.2	6.4
2001	15.11	14.95	7.0	6.8
2002	14.45	14.95	3.2	3.3
2003	7.46	14.95[1]	2.3	2.6
2004	7.48	14.95[1]	2.2	2.5
2005	7.57	14.95[1]	1.7	1.8
2006	7.44	14.95[1]	1.9	1.9
2007	7.37	14.95[1]	2.2	2.4
2008	7.49	14.95[1]	3.3[2]	3.3

1 Fifty percent of the TACC shelved for the season
2 Fishers on six of the eleven vessels given incentive to sort above MSL to increase market value, and changes in sorting potentially result in lower catch rates compared to previous years.

Table 4: Oyster catches reported from vessels fishing under special permits to the Bluff Oyster Enhancement Company 1992–2000. Fishing took place over the summer breeding season (November–February) rather than the winter season (March–August) of commercial fishing. Reported catch and permit allocations 1992–93 to 1995–96 converted sacks to numbers assuming a rate of 774 oysters per sack. No special permit was issued in 1998 (-).

Summer	Reported catch (millions of oysters)	Permit allocation (millions of oysters)
1992–93	2.43	3.10
1993–94	3.09	3.10
1994–95	3.03	3.10
1995–96	0.93	0.93
1996–97	0.20	0.88
1997–98	0.72	0.72
1998–99	-	-
1999–2000	1.00	1.00

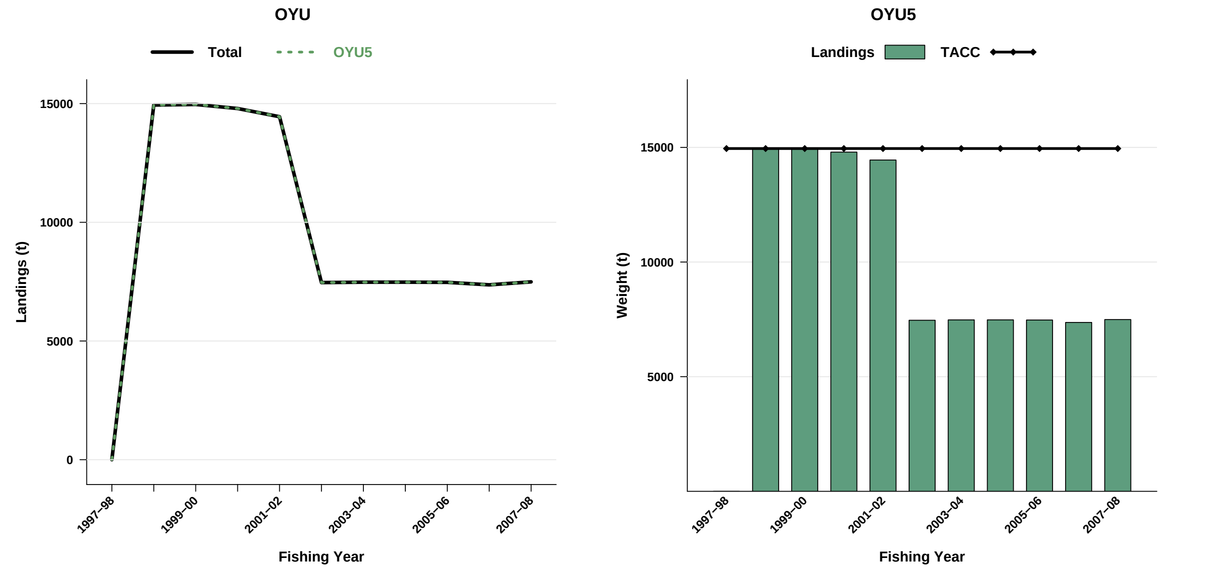

Figure 2: Left: Landings for individual OYU stocks and the sum total of all OYU landings (solid line) throughout time. Right: Historical landings and TACC for OYU5 (Foveaux Strait). Note that these figures do not show data prior to entry into the QMS.

1.2 Recreational Fishery

In 2002, Fisheries Officers estimated that between 70 and 100 recreational vessels were fishing from Bluff and smaller numbers from Riverton and Colac Bay. Most of these vessels are fitted with GPS and capable of fishing Foveaux Strait with up to four recreational fishers on board. Recreational fishers may take 50 oysters per day during the open season. A charter boat fleet at Stewart Island, Bluff, and Riverton target oysters during the oyster season. Around seventeen include oyster dredging and oyster diving trips as part of their winter programme. Some vessels can have up to 15–20 fishers out for the day (each returning with 50 oysters).

Four surveys of recreational fishing have been conducted to estimate recreational harvest, the South region 1991–92 survey and the 1996 (Bradford, 1998), 1999-2001 (Boyd & Reilly, 2004) and 2000-01 (Boyd et al, 2004) national telephone diary surveys. However, the catch of oysters cannot be reliably quantified from these surveys because of the small number of local respondents who reported catches of oysters in their diaries and the identification of oysters as either dredge oysters or generic oysters. The Southland Recreational Marine Fishers Association estimated the annual recreational catch of oysters in Foveaux Strait in 1995 to be about 301 860 oysters.

The commercial oyster fleet are a major contributor to the level of recreational harvest. Commercial fishers are entitled to 50 oysters each fisher each day, with each commercial vessel's crew potentially taking up to 300 oysters as recreational catch each day. These catches are reported in Catch and Effort Landing Returns (CELR) under s111 of the Fisheries Act. Commercial fishers took 141 587 oysters under recreational bag limits during the 2008 oyster season. Recreational catch taken on commercial vessels is shown in Table 5.

Table 5: Reported annual recreational catch (numbers of oysters) taken from commercial vessels 2002–08 (Ministry of Fisheries CELR data) and reported customary catch (numbers of oysters) 1998–2008 (Tangata taiki data collected by Ngai Tahu). NA denotes no data available.

Year	Recreational catch from commercial vessels	Customary catch
1998	NA	143 940 [1]
1999	NA	177 360
2000	NA	223 332
2001	NA	259 243
2002	236 103	184 335
2003	282 645	157 980
2004	146 567	127 708
2005	190 345	76 464
2006	139 252	85 312
2007	90 544	109 260
2008	141 587	202 952

1 Customary catch reported for the period 1 July to 31 December only

The total recreational catch is about 0.5 million oysters. The reliability of this estimate is not known.

1.3 Maori customary fisheries

Reporting of Maori customary harvest is specified in the Fisheries (South Island Customary Fisheries) Regulations 1999. Ngai Tahu administers reporting of customary catch of Foveaux Strait oysters to the Ministry of Fisheries. Customary catch is reported in the quarter it is summarized (landing dates not reported). Little customary fishing is believed to take place between 31 August and mid November while oysters are spawning, and no customary permits are issued for the quarter October to December. Therefore data are likely to represent annual catches. Reported customary catch for 1998 to 2009 is given in Table 5. Customary catch in 2008 was 0.2 million oysters.

1.4 Illegal catch

The Ministry of Fisheries estimated the illegal catch of oysters for the 1998 and 1999 fishing years to be about 10% of the total non-commercial catch (about 66 000 oysters). The estimate of non-commercial catch summed estimates of customary catch (~160 000), recreational catch (~302 000 oysters), and the recreational catch from commercial vessels (~204 000). However, because the estimate of illegal catch cannot be verified, the Working Group is not in a position to modify or determine its acceptability. There is no further information available.

1.5 Other Sources of Mortality

1.5.1 Mortality caused by *Bonamia exitiosa*

Bonamia exitiosa is a haemocritic, haplosporid parasite (infects mainly haemocytes or blood cells) of flat oysters. It is known to infect *Ostrea chilensis* in New Zealand and Chile; *Ostrea angasi* in Australia; *Ostrea puelchana* in Argentina; *Ostrea* (*Ostreola*) *conchaphila* in California, USA; *Ostrea edulis* in Atlantic Spain, probably Gulf of Manfredo, Italy (Adriatic); *Ostrea stentina* in Tunisia, and possibly northern New Zealand (this isolate is also similar to *B. roughleyi*); and *Crassostrea ariakensis* in North Carolina, USA (Mike Hine, pers. comm.). Further, an unknown species of bonamia has been identified in two species of native oysters from Hawaii.

Mortality of oysters from *B. exitiosa* is a recurrent feature of the Foveaux Strait oyster population and the main driver of oyster abundance during epizootics. Large numbers of new clocks (shells of oysters that had died within six months) and oysters in poor condition, both indicative of *B. exitiosa* epizootics, were recorded as long ago as 1906. *B. exitiosa* has been identified in preserved oyster tissues sampled in 1964, at the end of an epizootic that caused a downturn in the fishery (Cranfield et al 2005) and originally attributed to *Bucephalus longicornutus* (Hine and Jones 1994) A *B. exitiosa* epizootic was confirmed in the Foveaux Strait oyster fishery in 1986–92 and again in 2000–09. Prevalence of infection between 1996 and 2000 was not sampled, but is thought to be low (almost undetectable) from the low numbers of new clocks recorded in biennial oyster population surveys.

In the early stages of an epizootic when bonamia is spreading through the fishery, infection and mortality are high and can be detected throughout the year, but in later stages, infection is generally lower, and infection and mortality detected mainly from January to March. The annual cycle of infection is described by Hine (1991). The parasite transmits directly, oyster to oyster, and disease spread is thought to be related to oyster density. Some oysters appear more tolerant of infection than others (Hine 1996). The relationship between the intensity and prevalence of infection in one year, the density of oysters, and the probability of oyster mortality the following year are poorly understood (see Sullivan et al, 2005).

Mortality from *B. exitiosa* 1986–92 reduced the Foveaux Strait oyster population to below 10% of its pre disease level. In the absence of bonamia, the oyster population increased to relatively high oyster densities in the areas first affected by bonamia infection by 1999. Another *B. exitiosa* epizootic was detected in 2000 (Dunn et al, 2000), and proceeded to spread and cause mortality in a similar pattern to the previous epizootic. Estimated mortality of recruited oysters in 2001 was about 12% (95% confidence interval 11–13%), with peak mortality of 56% (95% confidence interval 48–64%). Between 2000 and 2002, infection from *B. exitiosa* caused mortality in 66% of recruited oyster in Foveaux Strait and 72% by 2005. Mortality of oysters in designated commercial fishery areas was 50% by 2002, and oyster density reduced to one third. Since 2005, mortality from bonamia has been relatively low (<10% of recruited oysters).

It is not known whether other disease agents (including an apicomplexan, *Bucephalus* sp., coccidian, and microsporidian) contributed to or caused mortality in oysters during the 1986–92 and 2000–09 epizootics.

Preliminary analysis of the distribution of fishing effort accounting for 100% of the annual catch form fishers' logbook data and the distribution of prevalence and intensity of bonamia infection in oysters from fishery independent surveys between 2006 and 2009 show no relationship. No direct and immediate effect of oyster dredging on diseases status can be determined.

1.5.2 Incidental mortality caused by heavy dredges

Since 1965, heavy double bit double ring bag dredges have been used in the fishery. The dredges weighed 410 kg when first introduced, and current dredge weight range from 460 kg to 530 kg. These dredges are significantly heavier than the single bit single ring bag dredges employed between 1913 and 1960s.

Incidental mortality of oysters from dredging with light (320 kg) and heavy (550 kg) dredges was compared experimentally in March 1997 (Cranfield et al, 1997). Oysters in the experiment had only a single encounter with the dredge. Numbers of dead oysters were counted at the end of the experiment, seven days after dredging. The experiment found that mortality was inversely proportional to the size of oysters damaged and that lighter dredges damaged and killed fewer oysters. Recruit size oysters appeared to be quite robust (1–2% mortality) and few were damaged, smaller oysters (10–57 mm in length) less so (6–8%), but spat were very fragile and many were killed especially by the heavy commercial dredge (mortality of spat below 10 mm in height ranged from 19–36%). Incidental mortality from dredging may reduce subsequent recruitment in heavily fished areas but is unlikely to be important once oysters are recruited. The mortality demonstrated experimentally here has not been scaled to the size of the fishery and therefore its importance cannot be assessed.

2. BIOLOGY

Ostrea chilensis is a protandrous hermaphrodite that may breed all year round, but breeding peaks in the spring and summer months. Females produce few large (280–290 µm) yolky eggs, which after fertilisation continue to develop to pediveligers in the inhalant chamber for 18–32 days (depending on temperature). Most larvae are thought to settle immediately on release (at a size of 444–521 µm) and seldom disperse more than a few centimetres from the parent oyster. Some larvae are released early, at smaller sizes and spend some time in the plankton, and are capable of dispersing widely. Little is known about the timing and proportion of larvae released early in the plankton, and how this strategy may vary spatially and temporally, both within natal populations and the fishery.

In Foveaux Strait spat settlement is primarily during the summer months from December to February. Mean fertility of incubating oysters in Foveaux Strait was determined to be 5.09 x 10^4 larvae, and only 6–18% of the sexually mature oysters spawned as females each year.

2.1 Recruitment

Little data are available on recruitment. Stock recruitment relationships for the Foveaux Strait dredge oyster are unknown, but most oysters, surviving post settlement, are typically found on live oysters, and to a lesser extent, oyster shell and circular saw *Astraea heliotropium* (Keith Michael, NIWA, pers. comm.). Generally, recruitment of sessile organisms is highly variable and often environmentally and predation driven (see Jamieson & Campbell, 1998; Cranfield, 1979). About two percent of oyster spat survive the first winter; most mortality appears to result from predation by polychaetes, crabs, and small gastropods. Although settlement predominates on under surfaces of oysters and shell, most surviving spat are attached to the left (curved and generally uppermost) valve of living oysters. Mean density of six month old oyster spat settled on spat plates at six sites in western and eastern Foveaux Strait over the summer of 1999–2000 was 1 700m^2 (range 850–2 900m^2) (Cranfield et al unpublished data).

A strong recruitment pulse was observed in the fishery between 1993 and 2000, suggesting that high levels of recruitment are plausible during periods of low abundance. Between 1999 and 2005, when stock levels were low, the numbers of small oysters found in population surveys had remained relatively high. Since 2007, the numbers of small oysters estimated from surveys have decreased, but may represent a time-lag between low population levels and reduced recruitment, and when the low recruitment event becomes evident in the fishery. The OYU 5 stock assessment model estimates show recruitment strength below the long-term average since 2002, when the oyster population was reduced to low levels by bonamia.

2.2 Growth

Growth rate of oysters has been estimated from height increment data. It varies between years and between areas of Foveaux Strait. Spat generally grow 5 to 10 mm in height by the winter after settlement. Mean height after one year is 18 to 25, 25 to 35 mm after two, 30 to 51 mm after three, 40 to 65 mm after four, and 65 to 75 mm after the fifth year. Oysters recruit to the legal-sized population (a legal-sized oyster will not pass through a 58 mm diameter ring, i.e. it must be at least 58 mm in the smaller of the two dimensions of height or length) at ages of 4–8 years.

Dunn et al (1998a) modelled the growth of a sample of oysters from four areas and grown in cages at the same site in Foveaux Strait. The oysters were measured at six-monthly intervals over three years. Dunn et al (1998a) found that there was evidence for strong seasonal variation in growth, with mean growth over the winter was zero or even slightly negative (the latter presumably due to shell abrasion). Length-based growth parameters from this study are shown in Table 6.

The complexity of these estimates cannot easily be reproduced within the population model and hence the data were re-fitted using maximum likelihood von Bertalanffy growth model based on the parameterisation of Francis (see Dunn, 2005).

Winter length measurements were ignored, and hence annual growth increment measurements only were considered. The growth parameters at $\alpha = 30$ and $\beta = 55$ were estimated outside the population model, as $g_\alpha = 11.91$ mm and $g_\beta = 3.61$ mm; variation in growth had an estimated CV of c=0.31 and $\sigma_{\min}$=4.45 mm; and estimated measurement error σ_E was 2.12 mm.

2.3 Maturity

Jeffs & Hickman (2000) estimated measures of maturity from the re-analysis of sectioned oyster gonads sampled at around monthly intervals from four sites in Foveaux Strait from April 1970 to April 1971. The sites were located across the main commercial fishery areas. These samples were collected prior to the 1986–92 epizootic, and represent the reproductive cycle before major disruption to the population structure caused by bonamia mortality. Analysis of these samples revealed that oysters were protandrous, maturing first as males by 20 mm in shell height. Beyond 50 mm, most oysters developed ova while continuing to produce sperm, although oysters did not begin brooding larvae until 60 mm. Considerable quantities of ova were present in oysters throughout the year, but only a very small proportion of oysters spawned ova from July to December with a peak in October. Oysters commonly contained and released sperm throughout the year, although peak spawning was from November to March. The phagocytosis of reproductive material from the follicles of oysters was present in a small proportion of oysters throughout the year. However, it was much more common from January to March amongst both male and female reproductive material, including smaller (less than 50 mm), solely-male oysters.

Dunn 2005 used the data from Jeffs & Hickman (2000) for the proportion of oysters with female ova, during the months of October–March, were used to determine the maturity ogive within the model. Figure 3 shows the estimated proportions mature (i.e., proportions of oysters with presence of female ova) by length class, along with exact 95% confidence intervals.

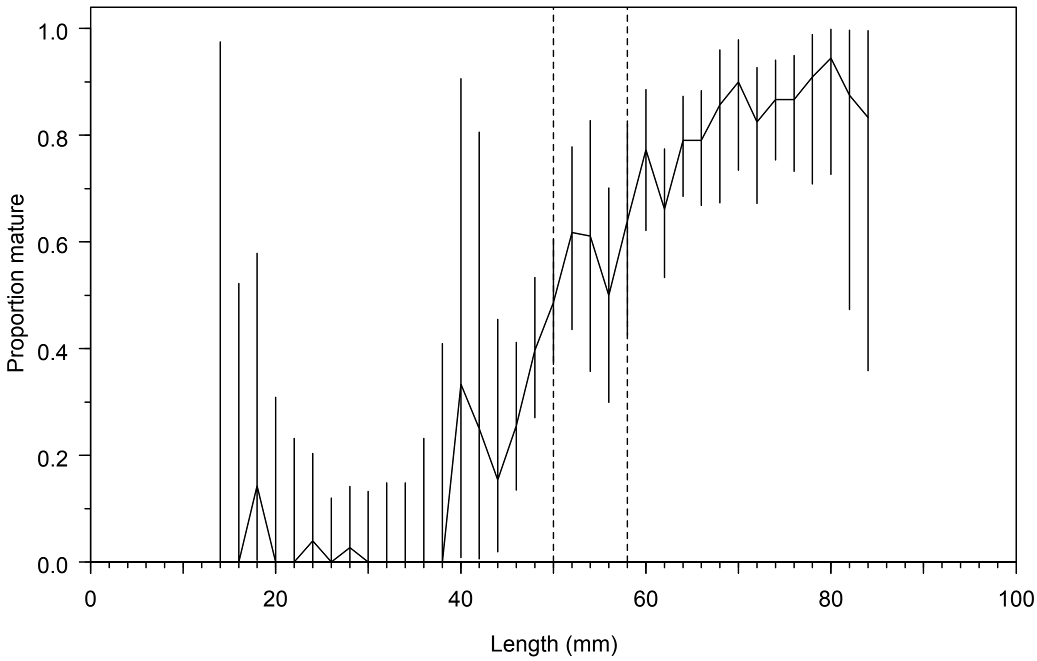

Figure 3: Proportions of mature oysters (defined as the proportion of oysters with female ova) by length from the analysis of data of Jeffs & Hickman (2000). Vertical bars give exact 95% confidence intervals, and dashed lines separate the small (<50 mm), pre-recruit (≥ 50 mm and <58 mm), and recruit (≥ 58 mm) size groups.

2.4 Natural Mortality

Dunn et al (1998b) estimated natural mortality for the years 1974 to 1986 from the reanalysis of tagging data. Estimated natural mortality was found to increase from 0.017 y^{-1} to 0.188 y^{-1} from 1974-1986 for oysters released in 1974, and from 0.009 y^{-1} to 0.199 y^{-1} for oysters released in 1973. The weighted average instantaneous natural mortality, M, for all data combined for the years from 1974 to 1986 was 0.042 y^{-1}.

A constant value for natural mortality of 0.1 y^{-1} was assumed, implying a maximum age (at which 1% survive) of 36 years. This assumption was based on estimates of M from Dunn et al (1998b) and two oysters tagged at recruit size (one from 1973 and one from 1976 or 1977) and recaptured (live) in early 2003 (K.P. Michael, NIWA, pers. comm.). These data suggest the value of M plus F was not high, as at least two oysters lived to recruit size and survived a further 26–29 years.

Table 6: Estimates of biological parameters

Fishstock		Estimate	Source
1. Natural mortality (*M*)			
OYU 5		0.075	Dunn et al (1998b)
		Assumed 0.1	Allen (1979)
		Assumed 0.1	Dunn (2007)
2. Length-based growth parameters from Dunn et al 1998a			

Length-based growth was estimated from model 3, is presented below. Growth is given for change in diameter.

$$\Delta l = (L_{\infty_{area}} - l1)(1 - e^{-k_{area+year}(\Delta t + \phi)}) - \varepsilon$$

Estimated parameter values (and 95% confidence intervals)

L_∞	Area A	92.2 mm (86.7-97.9)
	Bird I.	76.2 mm (73.5-78.9)
	Lee Bay	77.8 mm (73.4-81.4)
	Saddle	81.0 mm (77.3-84.9)
k	1979	(reference year)
	1980	-0.29 (-0.33– -0.25)
	1981	0.02 (-0.02 – 0.06)
	Area A	0.48 (0.41-0.54)
	Bird I.	0.85 (0.76-0.94)
	Lee Bay	0.77 (0.68-0.86)
	Saddle	0.51 (0.50-0.52)
ϕ		-0.03

3. Size at sexual maturity (Females)		
50 mm diameter (40 mm height)		Cranfield & Allen (1977)
50 mm in length		Jeffs & Hickman (2000)
4. Percentage of population breeding as females annually		
Foveaux Strait	6-18%	Cranfield & Allen (1977)
Foveaux Strait	~50%	Jeffs & Hickman (2000)

2.5 Disease Mortality

Data on disease mortality events are limited. Anecdotal reports exist of a mortality events indicated by large numbers of “clocks” (the articulated shells of recently-dead oysters with the ligament attaching the two valves intact) from the late 1940’s to 1960–63. The reported proportions of clocks to live oysters are similar to those found in abundance surveys during the *B. exitiosa* epidemics in the early 1990s and early 2000s. Hine (1996) later noted that the most likely cause of the mortality during the 1960s was *B. exitiosa*.

Dunn (2005) assumed that the relationship between disease mortality, oyster length, or oyster maturity was the same as the maturity ogive. B. Diggles (unpublished results) analysed 500 oysters from a survey on January 2004 for *B. exitiosa* infection, sex, and maturity with lengths between 24 and 81 mm. These data provide information on the disease selectivity of oysters, and can be used to determine a length-based selectivity of *B. exitiosa* (Figure 4).

NIWA studies (unpublished data) show category 3 infections are elevated and systemic, with minor tissue damage throughout the host, and these infections rapidly progress to category and 5 infections were tissue damage is extreme throughout the animal leading to death. The proportion of oysters with category 3 or greater infections are used to project oyster mortality likely to occur between the bonamia surveys and the early part of the following oyster season. Projected mortality with reference to commercial landings is given in Table 7.

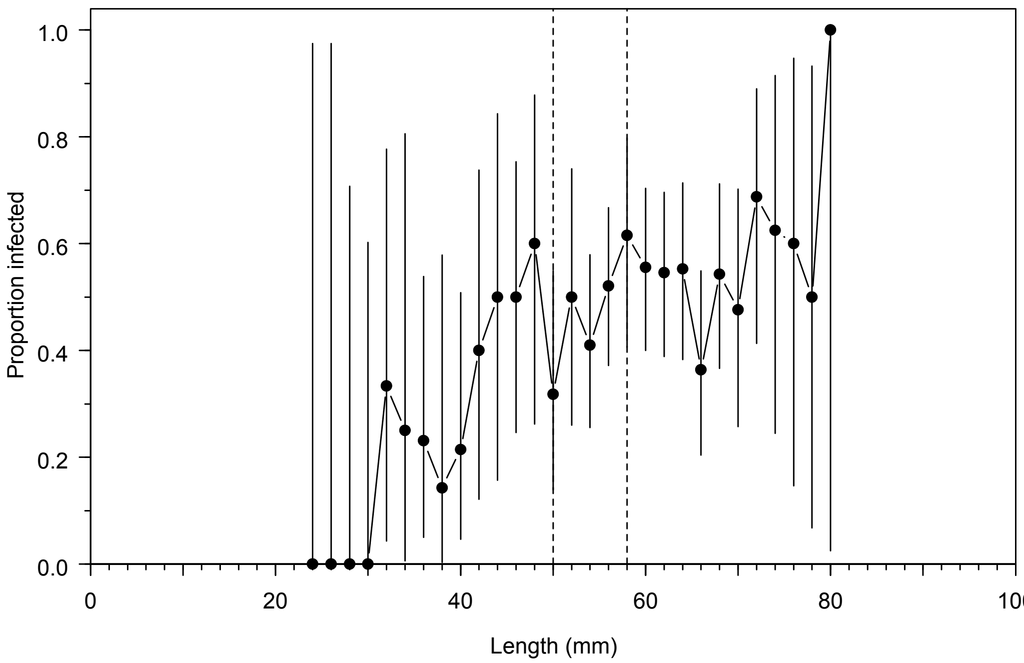

Figure 4: Proportions of oysters (and 95% confidence intervals) with a *B. exitiosa* infection of level 1+ from *B. exitiosa* histological sampling from the January 2004 surveys by length (B. Diggles, unpublished results). Dashed lines separate the small (<50 mm), pre-recruit (≥ 50 mm and <58 mm), and recruit (≥ 58 mm) size groups.

Table 7: Projected oyster mortality from category 3 and greater *B. exitiosa* infections. Projected percent of category 3 and greater infection over the entire population (Projected 3+), projected mortality in millions of oysters (Mortality), and commercial landing from the oyster season following the disease survey in millions of oysters (Landings). No data denoted by -.

Oyster season	Projected %3+	Mortality	Landings
2006	5.0	14	7.44
2007	6.9	43	7.37
2008	3.3	23	7.49
2009	6.3	46	–

3. STOCKS AND AREAS

The Foveaux Strait oyster stock area (OYU 5) covers 3300 km^2, but oysters distributed over some 1200 km^2. Almost all the commercial fishery operates in the 1999 oyster survey area, less than 1055 km^2. Only a small proportion of this commercial fishery area supports commercial densities of oysters and is regularly fished. In 1975, the oyster survey area encompassed almost all the then commercial fishery at that time and covered 374 km^2, but commercial oyster areas covered only 12 km^2 (Allen & Cranfield 1979). At that time, the oyster fishery consisted of a number of discrete small dense patches generally separated by extensive areas of barren ground, 91% of the total oyster population was located in about 50 patches.

Throughout the years, high catches of oysters have been confined to the same locations suggesting that these localised patches of oysters have remained stable in position over the history of the fishery. Between 1986 and 1992, mortality from *B. exitiosa* progressively destroyed most of the dense patches of oysters. This catastrophic mortality in the established fishery area (the 1975–76 survey area) forced fishers to expand the area fished ahead of the wave of mortality (Doonan et al, 1994).

The Foveaux Strait oyster fishery has been managed as a single stock, and current stock assessments are undertaken in a fishery area defined by the 1999 survey area. Although fishing occasionally occurs outside of this area, oyster population size in these outer areas is small.

4. STOCK ASSESSMENT

4.1 Population estimates

Surveys of the Foveaux Strait oyster population have been reported since 1906, see Dunn (2005) and Sullivan et al (2005) for details since 1960. Early surveys 1906, 1926–1945 are summarised by Sorensen (1968). Two large surveys to map oyster density were carried out in 1960–62 by Stead (1971), and again in 1975 and 1976 by Cranfield & Allen (1979). The efficiency of the small dredge used in 1975 and 1976 was poorly estimated at that time and the population estimate from that survey was too inaccurate for use in management. The efficiency of that survey dredge was better estimated during the surveys of 1990 and this new estimate of efficiency for the dredge was used to re-estimate the oyster population in 1975–76 to give a more accurate estimate that is comparable with recent surveys (Doonan et al, 1994).

The absolute population size was estimated in 1990 using a stratified random dive survey. The efficiency of the small survey dredge and of commercial dredges was estimated by comparing oyster density in the same areas using these dredges with the density from the dive survey. In 1992 and 1993 the population was estimated from grid pattern dredge surveys. The population was estimated from stratified random surveys in March and October 1995, and in October 1997, 1999, 2001, 2002, January 2005, February 2007, and in February 2009. Surveys of the Foveaux Strait oyster population have been traditionally in October after the commercial oyster season had finished, when the seasonal mortality from B. exitiosa was at its lowest, and to allow sufficient time for the stock assessment process to be completed before the next oyster season began the following March. Population estimates from surveys in 1990–1997 used an estimate of dredge efficiency (0.164) and surveyed the whole fishery area with a two-phase random stratified design. Population estimates for these surveys are shown in Table 8. The 1999–2007 population surveys used a revised estimate of dredge efficiency (0.166) and used information from commercial, exploratory and background areas designated by fishers to stratify the surveys. Since 2003, population surveys have been combined with B. exitiosa surveys in February (see Michael et al, 2008 for details).

Surveys since October 1999 have retained the same survey strata, although strata have been partitioned and their designation as commercial (where fishing is likely to occur the following oyster season), exploratory (areas with relatively high densities of pre-recruit oysters likely to support fishing in the near future), and background areas (with low densities of oyster, unlikely to be fished) changed to reflect changes in the distributions of oyster densities. The designations of strata are based on the distribution of oyster densities from the previous survey, from information in skippers' logbooks, skippers' input, and historical survey data (Figure 5)

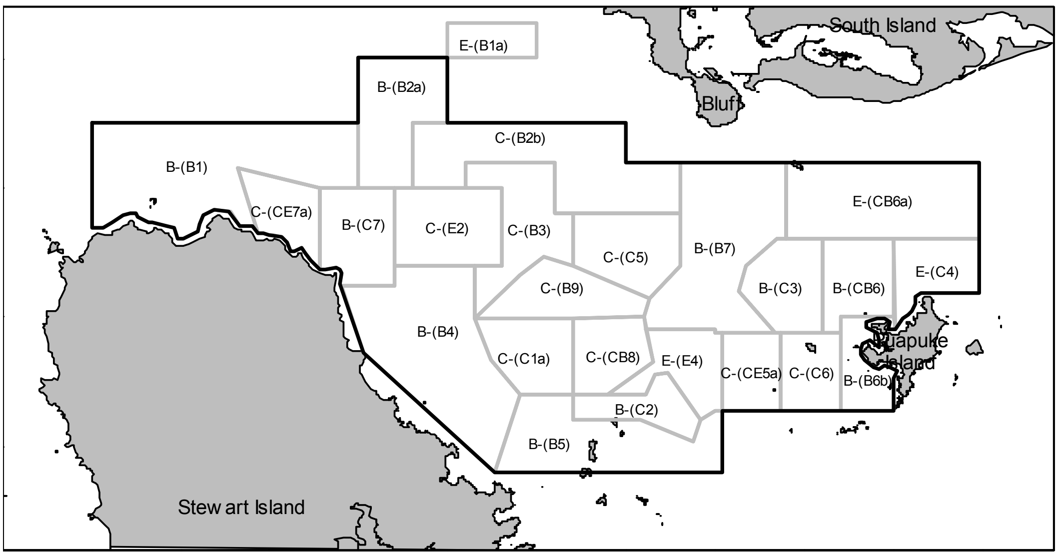

Figure 5: The 1999 survey area and survey strata (black lines), sampled in February 2009. Strata designated commercial by oyster skippers are those with a "C" prefix. Exploratory strata have an "E" prefix and background strata "B". Original designation in 1999 shown in brackets. B1a is a new stratum added in the 2007 survey and the stratum previously B2 partitioned into two (B2a and B2b) to better delineate oyster densities.

Surveys estimate the absolute population size of three size groups of oysters: recruits (unable to pass through a 58 mm internal diameter ring), and pre-recruits (able to pass through a 58 mm internal diameter ring, but unable to pass through a 50 mm ring), and small oysters (able to pass through a 50 mm internal diameter ring and down to 10 mm in length). Population estimates for these three size groups of oyster from 1960–64 to 2009 are shown in Table 8 and for more details see Fu et al (2009)

Table 8: Absolute population estimates for Foveaux Strait oysters within the 1999 survey area (1055 km^2) for surveys 1960–2009. Recruited, pre-recruit, and small oyster population size estimates (millions of oysters) and c.v.s. Survey designs (Design) were either grid surveys (Grid) or stratified random surveys (SR). For longer and more detailed data 1960–2009 see Fu et al (2009). '–' indicates not surveyed.

Date	Design	Number of stations	Recruits (millions)	c.v.	Pre-recruits (millions)	c.v.	Small (millions)	c.v.
1960–64	Grid	310	3059	0.21	-	-	-	-
July 1990	Grid	293	707	0.11	-	-	-	-
October 1990	SR	116	623	0.12	-	-	-	-
March 1992	Grid	293	285	0.12	-	-	-	-
October 1992	Grid	177	397	0.10	383	0.11	1004	0.10
March 1995	SR	49	576	0.25	401	0.28	402	0.25
October 1995	SR	154	782	0.11	380	0.10	718	0.21
October 1997	SR	107	660	0.14	727	0.14	918	0.14
October 1999	SR	199	1453	0.16	896	0.12	1364	0.11
October 2001	SR	192	995	0.11	872	0.12	1410	0.12
October 2002	SR	155	502	0.14	520	0.11	1243	0.10
January 2005	SR	80	408	0.13	415	0.15	1345	0.12
February 2007	SR	101	663	0.11	486	0.12	879	0.10
February 2009	SR	111	720	0.08	354	0.10	903	0.10

4.2 Historical estimates of the commercial population and yield

Since 1996, yield was estimated for the commercial population (the part of Foveaux Strait likely to be fished), to prevent recruitment over fishing in areas where oyster populations were rebuilding after *B. exitiosa* mortality. Estimates of commercial population size between 1996 and 1999 used the portion of the population over 400 oysters per tow (roughly equivalent to a commercial catch rate of 6–8 sacks per hour considered economic by fishers in the 1970s and early 1980s) from the entire Foveaux Strait fishery area. A commercial catch rate of 6–8 sacks per hour has no biological basis, but has been used as an indicator of commercial oyster densities. Estimates of the proportion of oysters above 400 oysters per standard survey tow over the entire fishery area 2001–09 are given in Table 9.

From 2000, estimates of commercial population size were based on estimates of the entire recruited oyster population in areas designated as 'commercial' by fishers (Michael et al, 2004), commercial fishery areas in 2009 are shown in Figure 5. The mean commercial population size has increased from 144 million oysters (95% C.I. 93–216) in October 2002 to 196 million (95% C.I.s 124–300) in 2007, and 361 million (95% C.I. 227–549) in 2009. The area of the designated commercial areas increased from 173 km^2 in 2002 to 367 km^2 in 2005, and remained the same since. Oyster density was halved from 0.83 oysters/m^2 in 2002 to 0.44/m^2 in 2005, and has increased to 0.97 /m^2 in 2009.

Table 9: Estimates of the proportion of oysters above 400 oysters per standard survey tow over the entire fishery area 2001–09; the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (CV) of the population estimate, mean population size (Mean population with upper and lower 95 % confidence intervals in parenthesis), and the area of each survey (Area).

Year	No. stations	Mean density	s.d.	CV.	Mean	population 95% CI	Area km^2
2001	192	0.59	0.10	0.17	624	(359–1012)	1054
2002	155	0.17	0.06	0.33	178	(57–331)	1054
2005	80	0.03	0.02	0.58	33	(0–78)	1054
2007	104	0.19	0.07	0.36	204	(60–403)	1070
2009	115	0.24	0.06	0.23	257	(129–441)	1070

A possible and significant source of error in the estimates of population size could be changes in dredge efficiency. Dredge efficiency was last calculated in 1990. The distribution of oysters, the structure of commercial fishery areas, the substrate and epifauna, and the number of clocks (shells of dead oysters) are likely to have changed since then and may effect dredge efficiency.

4.3 Stock assessment

Before 2004 the Foveaux Strait oyster fishery was managed by current annual yield (CAY, Method 1, see Sullivan et al., 2005) based on survey estimates of the population in designated commercial fishery areas. Since 2004, the TACC has been based on estimates of recruit size stock abundance from the Foveaux Strait oyster stock assessment model (Dunn, 2005, 2007) and projections of future recruit size stock abundance under different catch limits and heightened mortality from *B. exitiosa*. A spatially explicit epidemiological model of *B. exitiosa* (Gilbert & Michael, 2006) may incorporate the stock assessment model in the future to provide stock assessment on sub areas of the fishery.

In 2004, Dunn (2005) presented a Bayesian, length-based single-sex, stock assessment model for Foveaux Strait dredge oysters using the general-purpose stock assessment program CASAL (Bull et al, 2005). That model was updated in 2007 (Dunn unpublished) to account for new data available, and a more complex variant of that model was also investigated. The assessment was updated in 2009 to include data from the 2007–08 fishing year and the abundance indices from the February 2009 survey (Fu et al, 2009). The model inputs and results are summarised below.

4.4 Resource surveys and other abundance information

Resource surveys of Foveaux Strait dredge oysters have been conducted since 1906 (Hunter 1906). Re-analysed estimates of abundance were made for surveys since 1990, and were based on an estimate of the populations size within the 1999 survey area using the dredge calibration from the 1990 dredge/dive survey. These estimates were generated to provide a consistent time series over a constant region (Table 8).

Raw catch and effort data have been collected in the Foveaux Strait dredge oyster fishery since about 1948. The unstandardised CPUE indices (sacks per hour) were split into three series, namely (i) Series A, from 1948 to 1968 when the legal size was defined as 2.125 inches and the typical commercial dredge was about 3.35 m-wide with single-bit and single ring bag and weighing ~150 kg, (ii) Series B, from 1969 to 1984 when the legal size was 2.25 inches, and the typical commercial dredge was about 3.35 m-wide with double-bit and double ring bag and weighing ~ 400 kg, and (iii) Series C, years after 1984 when the typical commercial dredge was modified by increasing its weight up to 530 kg.

4.5 Length frequency of the winter season commercial catch

Length samples from the commercial catch were taken during the 2002 (Michael et al. 2004a), 2003, 2005 (Dunn & Michael 2006), 2006 (Dunn & Michael 2007), 2007 (Dunn & Michael 2008), and 2008 (Dunn. et al 2009) fishing seasons. In 2002, 15 580 oysters were measured (15 269 recruited and 311 pre-recruits); in 2003, 18 940 oysters were measured (18 189 recruited and 751 pre-recruits); in 2005, 6509 oysters were measured (6339 recruited and 170 pre-recruits); in 2006 6801 oysters were measured (6635 recruited and 166 pre-recruits); in 2007, 6829 oysters were measured (6734 recruited and 94 pre-recruits); and in 2008, 6831 oysters were measured (6733 recruited and 98 pre-recruits). These data were used to derive the estimates of the catch-at-length frequencies (with associated c.v.s).

4.6 Population length frequency estimates

Height data were collected on the October 1990 dive survey, and the 1960–64 dredge survey. Length data were collected from the 1926–27, 1999, and 2001 surveys. Only the height data (converted to length using the method described by Dunn (2005) from the October 1990 dive survey, and the length data from the 1999 and 2001 surveys were included in the assessment model as the population length frequency estimates.

4.7 Assessment model

The population model partitioned Foveaux Strait oysters into a single sex population, with length (i.e., the anterior-posterior axis) classes 2 mm to 100 mm, in groups of 2 mm, with the last group defined as oysters ≥ 100 mm. The stock was assumed to reside in a single, homogeneous area. The partition accounted for numbers of oyster by length class within an annual cycle, where movement between length classes was determined by the growth parameters. Oysters entered the partition following recruitment and were removed by natural mortality including disease mortality, and fishing mortality. The models annual cycle was divided into two time steps (Table 10).

Table 10: Annual cycle of the population model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.

Step	Period	Process	Proportion in time
1	Oct–Feb	Maturation	1.0
		Growth	1.0
		Natural mortality	0.5
		Fishing (summer) mortality	1.0
		B. exitiosa mortality	1.0
2	Mar–Sep	Recruitment	1.0
		Natural mortality	0.5
		Fishing (winter) mortality	1.0

Oysters were assumed to recruit at age 1+, with a Beverton-Holt stock recruitment relationship (with steepness 0.9) and length at recruitment defined by a normal distribution with mean 15.5 mm and c.v. 0.4. Relative year class strengths were assumed known and equal to initial recruitment for the years up to 1984 — nine years before the first available length and abundance data on small (oysters <50 mm minimum diameter) and pre-recruits (oysters between ≥ 50 to <58 mm minimum diameter) were available; otherwise relative year class strengths were assumed to average 1.0. Growth rates and natural mortality (M) were assumed known. Disease mortality is assumed to be zero in the years where there were no reports of unusual mortality, and otherwise estimated.

The models used seven selectivity ogives: the commercial fishing selectivity (assumed constant over all years and time steps of the fishery, aside from changes in the definition of legal size); a survey selectivity, which was then partitioned into three selectivities (one for each for each of the size-groups) — small (<50 mm minimum diameter), pre-recruit (≥ 50 mm and <58 mm minimum diameter), and recruit (≥ 58 mm minimum diameter); maturity ogive; and disease selectivity — assumed to follow a logistic curve equal to the maturity ogive. The selectivity ogives for fishing selectivity, maturity, and disease mortality were all assumed to be logistic. The survey selectivity ogives were assumed to be compound logistic with an additional parameter amin, that describes the minimum possible value of the logistic curve. Selectivity functions were fitted to length data from the survey proportions-at-length (survey selectivities), and to the commercial catch proportions-at-length (fishing selectivity).

The maximum exploitation rate (i.e., the ratio of the maximum catch to vulnerable numbers of oysters in any year) was assumed to be relatively high, and was set at 0.5. No data are available on the maximum exploitation rate, but the choice of this value can have the effect of determining the minimum possible virgin stock size (B_0) allowed by the model.

The model was run for the years 1907–2009. Catch data were available for the years 1907–2008, with the catch for 2009 assumed to be 7.5 million oysters. Catches occurred in both time steps — with special permit and some customary catch assigned to the 1st time step (summer fishing mortality), and commercial, recreational, remaining customary, and illegal catch assigned to the 2nd time step (winter fishing mortality).

The priors assumed for most parameters are summarised in Table 11. In general, ogive priors were chosen to be non-informative and were uniform across wide bounds. The prior for disease mortality was defined so that estimates of disease mortality were encouraged to be low. An informed prior was used when estimating the survey catchability, where a reasonably strong lognormal prior was used, with mean 1.0 and c.v. 0.2.

Table 11: The priors assumed for key parameters. The parameters are mean and c.v. for lognormal (in natural space); and mean and s.d. for normal.

Parameter	Distribution	Parameters		Bounds	
CPUE q	Uniform-log	–	–	$1x10^{-8}$	0.1
1976 survey q	Lognormal	0.5	0.3	0.15	0.95
Mark-recapture survey q	Lognormal	0.5	0.3	0.10	0.90
YCS	Lognormal	1.0	1.0	0.01	100.0
Disease mortality	Normal	-0.2	0.2	0.00	0.80

4.8 Results

Model estimates of numbers of oysters were made using the biological parameters and model input parameters described above. Two model runs were considered. The '2009 basic model' updated the basic model in the 2007 assessment with catch and CPUE data for the 2007 and 2008 fishing years, the inclusion of the February 2009 biomass survey indices, and an assumed catch of 7.5 million oysters in 2009. The '2009 revised model' updated the 2007 revised model with similar input data. Table 12 described the two model runs.

Table 12: Model run labels and descriptions.

Model run	Description
2009 basic model	Growth parameters assumed fixed; annual disease rates estimated as independent variables; the disease selectivity was the same as the maturity ogive; Relative catchability q for the abundance surveys was fixed to be 1.
2009 revised model	Growth parameters estimated using tag-recapture data; annual disease rates assumed to be cubic-smooth; decoupled the maturity and disease selectivity ogive; Estimated relative catchability q for the abundance surveys;

A single Monte-Carlo Markov Chain (MCMC) was run on each model, with length 1.5x106 iterations including a burn-in of 0.5x106 iterations for the basic model. For the revised models, MCMC chains of length 6x106 iterations including a burn-in of 1x106 iterations were used. Final posterior distributions were derived from systematic sub-sampling ("thinning") of the chain, excluding the burn-in, to 1000 samples.

For both models, Model fits to recruit sized and pre-recruit sized dredge survey length frequencies, maturity data, and fishing length frequencies were adequate, although there was some evidence of over-fitting to the recruit sized length frequencies. Diagnostic plots of the combined fits to recruit, pre-recruit, and small dredge survey selectivities suggested that the parameterisation of selectivities for the three size groups (recruit, pre-recruit, and small) was adequate. Estimated CPUE q's showed an increase in relative catchability from series A and B to series C, possibly corresponding with improved technology and dredge size. The 1975–76 and mark-recapture abundance data contribute little to the model fits, as these series are short and are unrelated to other abundance data in the model. However, posterior distributions for all the catchability constants were relatively narrow. MPD model fits to abundance indices showed no strong evidence of poor fit to the data. However, most of the historical data provided to the model were derived from the catch-effort indices and it is not known how well these index abundance (although comparisons with survey data suggest that these are broadly informative).

Estimates of the disease mortality rate ranged from 0.0 up to a maximum of 0.80 y^{-1} (the upper bound) in the mid-1980s and early 2000s, and accounted for the dramatic declines in the abundance of oysters during periods of epidemic.

Estimates of relative year class strength were uncertain and variable, but suggest that there may have been a pulse of strong recruitment during the mid to late-1990s. Recent recruitment was estimated to be lower than average. However, without other, better, data on historical levels of recruitment, these estimates could not be validated.

The basic model suggested the virgin equilibrium spawning stock population size to be about 4 240 (3 790–4 820) million oysters, and the current spawning stock size to be 1 070 (940–1 210) million oysters (Table 13, Figure 6). The recruit-sized population was estimated as 820 (720–920) million.

The revised model run suggested a similar stock status as for the basic model, with slightly higher productivity resulting from a slightly faster growth rate. The relative estimates of B_0 from these model runs suggested much greater variability in the estimates of the initial population size, but estimates of the current status and recent change in the current status were very similar (see Table 13). Applying a smoothing penalty to the estimated annual disease mortality rates had little impact on the key estimated parameters of the model.

Table 13: Bayesian median and 95% credible intervals of B_0 (millions) and SSBs for 2007 and 2009 (millions).

Model	B_0	B_{2007}	B_{2009}
2009 basic model	4 200 (3 720–4 800)	1 010 (870–1 160)	1 070 (940–1 210)
2009 revised model	4 480 (2 730–7 970)	1 110 (660–2 000)	1 200 (700–2 160)

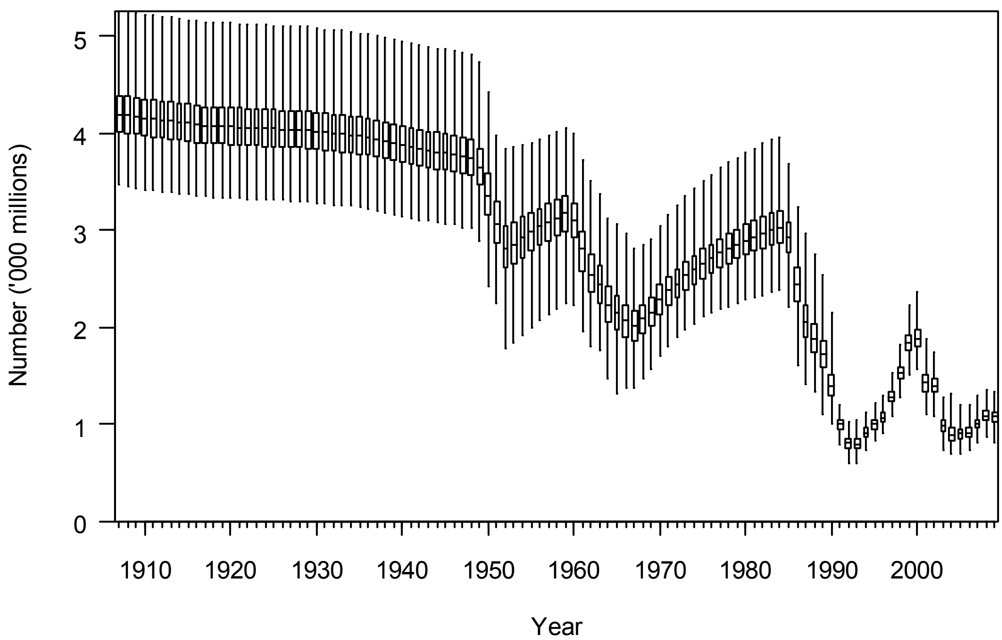

Figure 6: Estimated posterior distributions of SSBs. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

4.9 Projections

Projected stock estimates were made assuming that future recruitment will be log-normally distributed with mean 1.0 and standard deviation equal to the standard deviation of log of recruitment between 1985 and 2006 (i.e., 0.34 with 95% range 0.29–0.39). Projections were made assuming no future disease mortality and with future disease mortality assumed to be 0.0 y^{-1}, 0.10 y^{-1}, and 0.20 y^{-1}. Two future catch levels were considered each with 7.5 million oysters in 2009, and a future annual commercial catch of either 7.5 or 15 million oysters. Future customary, recreational and illegal catch were assumed equal to levels assumed for 2009. Projected output quantities are summarised in Tables 14–17. The plot of the median expected recruit sized population is given in Figure 7 and Figure 8.

Under the assumptions of future disease mortality, model projections of commercial catch at either 7.5 or 15 million showed little difference in expected population size For example, the projected population size in 2010 with a commercial catch of 7.5 million was less than 2% higher than that with a commercial catch of 15 million oysters. Depending on the level of assumed disease mortality, projected status in 2012 ranged from about 34% more than current levels (assuming no disease mortality) to a level about 23% less than the current level (assuming disease mortality of 0.2 y^{-1}) for the 2009 basic model, and from about 29% more than current levels (assuming no disease mortality) to a level about 12% less than the current level (assuming disease mortality of 0.2 y^{-1}) for the revised 2009 model.

Table 14: Median and 95% credible intervals of current spawning stock biomass 2009 (B_{2009}), and projected spawning stock biomass for 2010–2012 (B_{2008}–B_{2010}) as a percentage of B_0 with an assumption of a future catch of 7.5 million oysters in 2009 and 7.5 or 15 million oysters in 2010–2012, and disease mortality rate of 0.0, 0.1, or 0.2 y^{-1} for the 2009 basic model.

Disease mortality	Catch (millions)	B_{2009} (% B_0)	B_{2010} (% B_0)	B_{2011} (% B_0)	B_{2012} (% B_0)
0.00	7.5	25.9 (22.3–29.6)	25.4 (20.2–31.7)	29.8 (23.9–37.3)	34.4 (27.5–43.1)
	15.0	25.9 (22.3–29.6)	25.4 (20.2–31.7)	29.7 (23.7–37.1)	34.1 (27.3–42.8)
0.10	7.5	25.9 (22.3–29.6)	24.7 (19.6–30.8)	26.1 (20.8–32.7)	27.5 (22.0–34.8)
	15.0	25.9 (22.3–29.6)	24.7 (19.6–30.8)	26.0 (20.7–32.6)	27.2 (21.8–34.6)
0.20	7.5	25.9 (22.3–29.6)	24.0 (19.1–29.9)	22.9 (18.3–28.9)	22.4 (17.7–28.7)
	15.0	25.9 (22.3–29.6)	24.0 (19.1–29.9)	22.8 (18.1–28.8)	22.2 (17.5–28.5)

Table 15: Median and 95% credible intervals of expected recruit-sized stock abundance for 2009–2012 with an assumption of a future catch of 7.5 million oysters in 2009 and 7.5 or 15 million oysters in 2010–2012, and disease mortality rate of 0.0, 0.1, or 0.2 y^{-1} for the 2009 basic model.

Disease mortality	Catch (millions)	rB_{2009}/rB_{2009}	rB_{2010}/rB_{2009}	rB_{2011}/rB_{2009}	rB_{2012}/rB_{2009}
0.00	7.5	1.00 (1.00–1.00)	0.99 (0.81–1.16)	1.16 (0.95–1.38)	1.33 (1.09–1.63)
	15.0	1.00 (1.00–1.00)	0.99 (0.81–1.16)	1.15 (0.94–1.38)	1.32 (1.08–1.62)
0.10	7.5	1.00 (1.00–1.00)	0.95 (0.82–1.09)	1.01 (0.86–1.20)	1.07 (0.89–1.33)
	15.0	1.00 (1.00–1.00)	0.95 (0.82–1.09)	1.00 (0.85–1.19)	1.06 (0.88–1.32)
0.20	7.5	1.00 (1.00–1.00)	0.88 (0.76–1.01)	0.82 (0.70–0.98)	0.78 (0.64–0.98)
	15.0	1.00 (1.00–1.00)	0.88 (0.76–1.01)	0.81 (0.69–0.97)	0.77 (0.63–0.97)

Table 16: Median and 95% credible intervals of current spawning stock biomass 2009 (B_{2009}), and projected spawning stock biomass for 2010–2012 (B_{2008}–B_{2010}) as a percentage of B_0 with an assumption of a future catch of 7.5 million oysters in 2009 and 7.5 or 15 million oysters in 2010–2012, and disease mortality rate of 0.0, 0.1, or 0.2 y^{-1} for the 2009 revised model.

Disease mortality	Catch (millions)	B_{2009} (% B_0)	B_{2010} (% B_0)	B_{2011} (% B_0)	B_{2012} (% B_0)
0.00	7.5	27.9 (23.2–33.5)	26.8 (31.4–36.0)	31.4 (24.6–42.3)	36.0 (27.9–48.3)
	15.0	27.9 (23.2–33.5)	26.8 (20.8–35.5)	31.3 (24.5–42.2)	35.8 (27.7–48.1)
0.10	7.5	27.9 (23.2–33.5)	26.2 (20.3–34.6)	28.3 (22.0–38.1)	30.1 (23.2–40.7)
	15.0	27.9 (23.2–33.5)	26.2 (20.3–34.6)	28.1 (21.9–38.0)	29.9 (22.9–40.5)
0.20	7.5	27.9 (23.2–33.5)	25.6 (19.8–33.9)	25.5 (19.7–34.5)	25.5 (19.4–34.7)
	15.0	27.9 (23.2–33.5)	25.6 (19.8–33.9)	25.4 (19.6–34.4)	25.4(19.3– 34.5)

Table 17: Median and 95% credible intervals of expected recruit-sized stock abundance for 2009–2012 with an assumption of a future catch of 7.5 million oysters in 2009 and 7.5 or 15 million oysters in 2010–2012, and disease mortality rate of 0.0, 0.1, or 0.2 y^{-1} for the 2009 revised model.

Disease mortality	Catch (millions)	rB_{2009}/rB_{2009}	rB_{2010}/rB_{2009}	rB_{2011}/rB_{2009}	rB_{2012}/rB_{2009}
0.00	7.5	1.00 (1.00–1.00)	0.96 (0.83–1.13)	1.13 (0.95–1.37)	1.29 (1.08–1.60)
	15.0	1.00 (1.00–1.00)	0.96 (0.83–1.13)	1.13 (0.95–1.37)	1.29 (1.07–1.59)
0.10	7.5	1.00 (1.00–1.00)	0.96 (0.87–1.08)	1.04 (0.92–1.21)	1.12 (0.96–1.36)
	15.0	1.00 (1.00–1.00)	0.96 (0.87–1.08)	1.03 (0.91–1.21)	1.11 (0.95–1.36)
0.20	7.5	1.00 (1.00–1.00)	0.91 (0.82–1.02)	0.88 (0.78–1.03)	0.88 (0.75–1.08)
	15.0	1.00 (1.00–1.00)	0.91 (0.82–1.02)	0.88 (0.77–1.03)	0.87 (0.74–1.08)

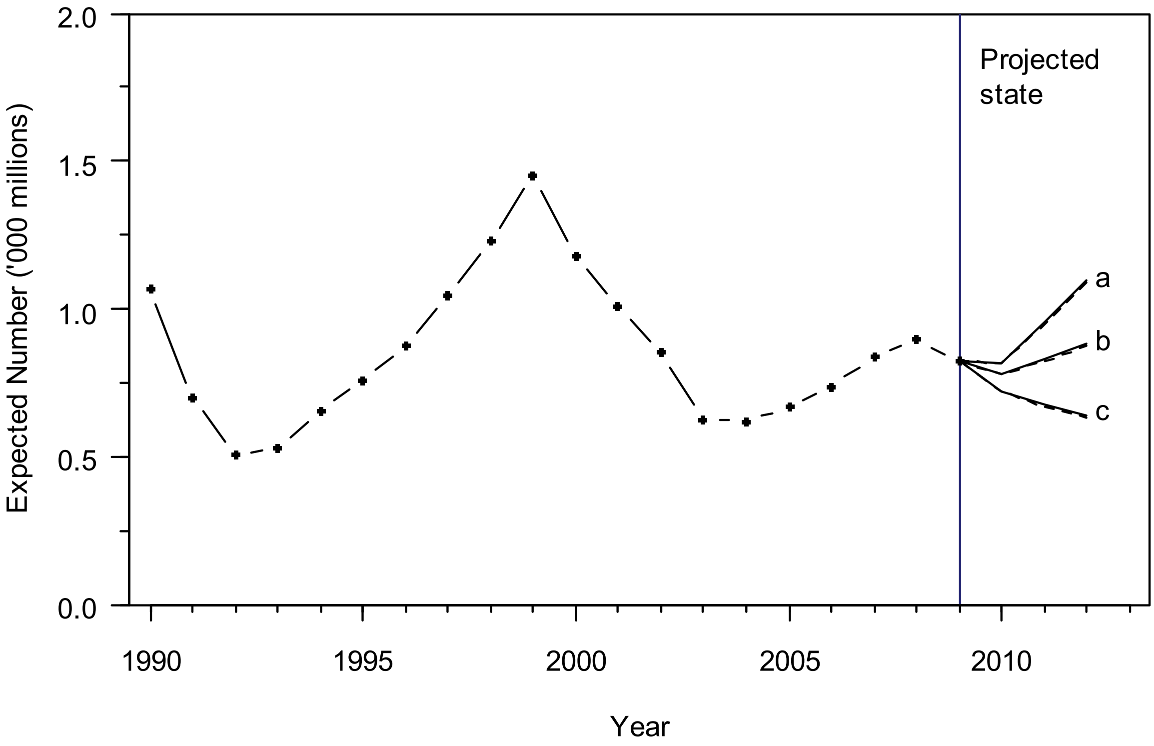

Figure 7: Estimates of recent recruit-sized stock abundance and projected recruit-sized stock abundance for 2010–2012 with catch of 7.5 (solid line) and 15 million oysters (dashed line), under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 y^{-1}, and (c) disease mortality of 0.20 y^{-1} for the 2009 basic model. Projections for catch limits of 7.5 and 15 million oysters for all levels of disease mortality are overlaid, i.e. there is little difference between catch limits.

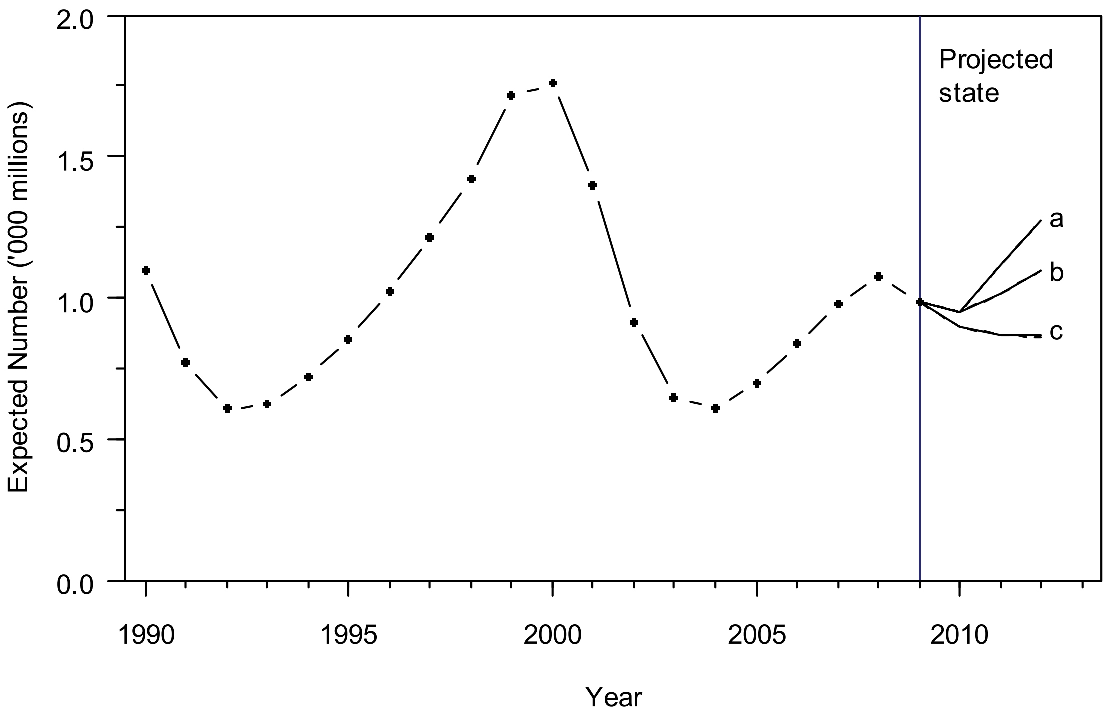

Figure 8: Estimates of recent recruit-sized stock abundance and projected recruit-sized stock abundance for 2010–2012 with catch of 7.5 (solid line) and 15 million oysters (dashed line), under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 y^{-1}, and (c) disease mortality of 0.20 y^{-1} for the 2009 revised model. Projections for catch limits of 7.5 and 15 million oysters for all levels of disease mortality are overlaid, i.e. there is little difference between catch limits.

5. OTHER FACTORS

5.1 Continuing mortality from *Bonamia exitiosa*

Since the present *Bonamia exitiosa* epizootic began in 2000, surveys of the oyster population found all areas with high densities of recruited oysters including the designated commercial areas had a high prevalence of infection. Mortality of oysters from 1999–2002 has reduced the oyster population to one-third of the population in 1999, 1461 to 502 million oysters. By October 2002, mortality from *B. exitiosa* infection had reduced both the numbers of commercial fishery areas and the oyster densities within them to low levels. Between October 2002 and January 2005, numbers of pre-recruit oysters entering the fishery exceeded mortality from *B. exitiosa* infection and this trend has continued through to 2009; the density and population size of recruited oysters has increased. Almost all rebuilding is occurring in western, central, and southern fishery areas, including the area where *B. exitiosa* infection was first detected in 2000. Bonamia is still causing mortality in eastern fishery areas, even though oyster densities are low.

In 2009, bonamia infection is still widespread in the fishery area. Prevalence of infection is lower than 2007 and the numbers of sample stations with infection have been slowly decreasing since February 2006. Intensity of infection has continued to increase since February 2006, suggesting more of the infected oysters are developing fatal infections.

Although the recruited oyster population has been increasing since 2005, mortality for bonamia is still considerably higher than the commercial catch. Based on the number of oysters sampled with category 3 or greater infection, the mortality of recruited oysters between surveys and the oyster seasons have been 14, 43, and 23 million oysters for years 2006 to 2008 respectively. Over the summer of 2009, new clocks indicated at least 4 million recruited oysters had died immediately prior to the survey and based on category 3 or greater infections, another 46 million oysters would die early in the 2009 oyster season. The 6.25% of oysters with fatal infections were expected to reduce the recruited oyster population from 725 (476–1081) million oysters to 679 (445–1014) million.

Trends in the population sizes of pre-recruit and small oysters show low populations of recruit sized oysters lead to declines in small and then pre-recruit oyster numbers, generally with a time lag of two years between size classes. Continuing bonamia mortality could reduce future recruitment.

6. STATUS OF THE STOCKS

Since 2004, model projections of recruit-sized stock abundance under different catch limits and levels of bonamia mortality have been used for the Foveaux Strait oyster stock assessment. In 2007, model estimates of population size were similar to projections from the 2005 stock assessment (622 million oysters). Disease mortality for 2007 and 2008 was estimated at 6.9% and 3.3%, and the population size of recruited oysters projected to increase to 815–852 million oysters in 2009 under a harvest limit of 7.5 million oysters.

All fishery indicators show an improvement in the status of the fishery to date, and the rate of rebuilding in the oyster population has been similar to the 1992–99 rebuild. Population sizes of recruited oysters (absolute, commercial, and portion above 400 oysters per survey tow) have increased as have oyster densities, especially in commercial fishery areas. However, oyster densities in commercial strata are only 40% of 1999–2001 levels. This improved status is reflected in catch rates; the fleet season average of 1.9 sacks per hour in 2005 has increased to 3.3 sacks per hour in 2008, and about 4 sacks per hour so far in the 2009 season (fishers' logbook data). The proportion of large sized oysters in the commercial catch has also increased, 53.6% of the catch ≥ 64 mm in 2007 compared with 61.6% in 2008. Incentives to sort for larger oysters with higher market value and to spread fishing effort (to prospect for new fishery areas that are rebuilding) has probably resulted in lower than normal catch rates and may contribute to changes in the size structure of landed oysters. The size of the recruited oyster population is lower that predicted by the 2007 stock assessment for the levels of bonamia mortality observed over that period (less than 10%), 725 million oysters estimated compared with 815–850 predicted.

Infection by bonamia in February 2009 was widespread, with remaining prevalence of infection slowly declining, and the proportion of sample sites with bonamia also declining, but the intensity of infection has increased. Patterns of infection by bonamia suggest intensification of infection within small areas and not the spreading wave infection described at the start of epizootics. There is no evidence of immediate and direct relationship between fishing and infection. Based on category 3 or greater infections, another 46 million oysters (6.25%) would die early in the 2009 oyster season, reducing the recruited oyster population from 725 to 679 million oysters. Although the intensity of bonamia infection has increased in 2009 (mean mortality increased from 3.3% in 2008 to 6.3 in 2009), it is below the level thought to have an effect on future stock increases. Continuing oyster mortality from bonamia and lower numbers of pre-recruit and small oysters introduces greater uncertainty around how this will affect the oyster population rebuild compared with 1992–1999 when there was an assumption of no heightened mortality from bonamia (there was no bonamia sampling from 1996, but no evidence from surveys to suggest heightened mortality).

Depending on the level of assumed disease mortality, the 2009 stock assessment shows the median projected status in 2012 ranges from 30% more than the current level (with nil disease mortality) to 23% below the current level (assuming disease mortality of 0.2 y^{-1}). For the current estimates of disease mortality, the model trajectories show the population size to remain about the same for a year and then continued, but slow rebuilding of the fishery. The decreased rate of projected rebuilding is due to relatively low numbers of pre-recruits and small oyster available to recruit to fishery in the short term. Although recruitment is expected to increase towards the long-term fishery mean, there is some uncertainty around the effects of continuing bonamia mortality on recruitment.

Few fishery specific data are available to assess the direct and indirect effects of oyster dredging on recruitment, growth, and mortality of oysters. Oyster dredging has been shown to increase the mortality of spat settled the previous summer; 36% of spat < 10 mm in length, in a single pass of a commercial dredge. A natural mortality of this size class, up to 90%, has been recorded for spat settled on artificial collectors and in the absence of dredging. Fishing effort has decreased from the levels of peak effort between the 1960s and 1980s.

While uncertainty exists in levels of future recruitment and continued *B. exitiosa* related mortality, projections from the Foveaux Strait oyster stock assessment model indicate that current catch limits are unlikely to have any significant impact on future stock levels.

Reported landings and catch limits for the 2007-08 fishing year are summarised in Table 18.

Table 18: Catch limits and reported landings for the 2007-08 fishing year.

Fishstock	Catch limit	Reported landings 2007-08
OYU 5	14.95	7.49

7. FOR FURTHER INFORMATION

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