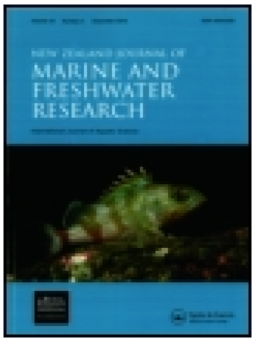

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Review

Folklore and chimerical numbers: review of a millennium of interaction between fur seals and humans in the New Zealand region

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Abstract The increase in numbers and range expansion of New Zealand fur seals (*Arctocephalus forsteri* Lesson) in the New Zealand region has prompted many people to comment on their effects on the marine and coastal environments. Overall there are anomalies in the data describing the distribution and abundance of fur seals in the New Zealand region, and there is a need for a better understanding of the interactions with humans and the impacts on the New Zealand environment. The distribution resulting from the present pattern of re-colonisation differs from the perception of their distribution before decimation by humans. We hypothesise that the pristine distribution was temperate rather than subantarctic. Previously published records which have documented changes in the abundance and distribution of the species are shown to be wanting. The most controversial management issue is interaction with commercial fisheries where we conclude that neither of the extreme options, culling of seals nor closure of some fishing grounds, is justified. Other issues addressed include tourism, *te tikanga Maori o mahinga kai* (the customary use of wildlife by Maori), and impact of fur seals on the coastal environment. This species offers a rare and exciting opportunity to test the theoretical processes of population expansion that can be investigated as a natural experiment. We suggest that the current management policy should remain unchanged until the current paucity of information on the degree of interaction between fur seals and humans has been addressed.

Keywords New Zealand fur seal; *Arctocephalus forsteri*; subsistence hunting; Maori; Moriori; commercial exploitation; Leslie matrix model; population estimates; population survey; fisheries interactions; tourism; *te tikanga Maori o mahinga kai*; management

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INTRODUCTION

Recently scientists, politicians, conservationists, and fishing industry representatives have commented on the real and postulated effects of an increasing New Zealand fur seal (*Arctocephalus forsteri* Lesson) population on human activities and the New Zealand environment. Overall there is a need for a better understanding of the distribution and abundance (e.g., Mattlin 1987; Crawley 1990; Duncan 1991; Taylor 1992; Richards 1994; Anon. 1995; Barton 1996), the interactions with humans (e.g., Talley 1991; Stevens 1999), and the impacts of fur seals on the New Zealand environment (e.g., Talley 1991; Anon. 1997; Best 1998; Stevens 1999). We saw a need therefore to expand our brief review of past exploitation (Lalas & Bradshaw 1998), to re-examine the available data on the current trends in *A. forsteri* abundance and distribution, and to explore the possible outcomes of an increasing fur seal population on human activity and the New Zealand environment.

New Zealand fur seals are distributed around New Zealand, the southern coastline of Australia, and Australasian temperate and subantarctic islands (Crawley 1990; Shaughnessy et al. 1994). Genetic analyses suggest that *A. forsteri* in New Zealand and the southern islands are genetically isolated from those in Australia (Lento et al. 1994, 1997), so we restrict our review to the population in the New Zealand region. Fur seals there were decimated by Polynesian hunting (Smith 1989) followed by European commercial sealing (Taylor 1982; Mattlin 1987). However, in recent years the population size has increased and the breeding distribution has expanded northward (Taylor 1982, 1992, 1996; Dix 1993a; Lalas & Harcourt 1995; Taylor et al. 1995; Lalas & Murphy 1998; Bradshaw et al. 2000).

In contrast to practically all indigenous fauna of New Zealand (King 1984; Stevens et al. 1995), New Zealand fur seals today appear largely unaffected by the human alteration of the New Zealand environment. However, many South Island colonies now abut rural and urban areas (Lalas & Bradshaw 1998) and this proximity to people has raised conservation issues that are not usually encountered with wildlife at more remote locations. In this paper we review the history of human exploitation and the subsequent population trends. Next we outline the anomalies in population estimates and census methods for New Zealand fur seals with a re-assessment of population models. We also discuss the evidence for competition between fur seals and commercial fisheries in light of population increases, and assess other types of impacts that an increasing fur seal population will have on humans and the environment. Finally, we offer future research and management recommendations.

REVIEW OF HISTORIC EXPLOITATION BY HUMANS

Prehistoric exploitation for food

Breeding by New Zealand fur seals was widespread around North Island and South Island before the arrival of Polynesians (Maori) in c. 1000 A.D. (Cassels 1984; Smith 1985, 1989). Subsistence hunting progressively eliminated fur seals from north to south and their mainland breeding range was confined to south-western South Island by the time of the initiation of continual European contact in the late 18th Century (Smith 1989) (Fig. 1: New Zealand locations mentioned in this review are shown in this figure, except those for which geographic co-ordinates are provided). This disappearance has been attributed to human impact because there is no evidence for any other environmental change that could have accounted for such a dramatic decrease in range (Anderson & McGlone 1992). The near elimination of the mainland fur seal population over 800 years could have resulted from only a 0.5% average annual rate of decrease in numbers (Lalas & Bradshaw 1998).

The importance of fur seals as a source of food for prehistoric Polynesians has been well documented (Cassels 1984; Davidson 1984; Smith 1989). Fur seals were a major source of meat through the early centuries of human settlement and matched the importance of moa (Dinornithiformes) at many sites (Davidson 1984). Localised extirpation of fur seals chronologically matched the extermination of moa and this paucity of large prey after 1500 A.D. caused a stabilisation (McGlone et al. 1994) or even a reduction (Anderson 1983) in the size of the human population in southern South Island. After the demise of breeding colonies, the taking of fur seals was restricted to non-breeders (Smith 1996).

The importance of fur seals has not been documented in Maori oral histories of the pre-European period. Fur seals were not mentioned in an account of Maori fishing methods by Best (1929). However, Beattie (1994) did describe hunting methods and utilisation of fur seals by South Island Maori, although his only report of breeding was at Taiaroa Head (45°46′S, 170°44′E), Otago Peninsula. Beattie (1994) mentioned only two other hunting locations: Banks Peninsula, notably around Akaroa (43°49′S, 172°57′E) and, less specifically, the western coast of South Island. The taking of fur seal pups at South Island through summer was shown in a Maori calendar for the harvest of food resources by Dacker (1990), but older animals were not mentioned. This record is inconsistent with the archaeological evidence that indicates both pups and adults were taken at breeding colonies (Smith 1985, 1989).

The prehistoric depletion of fur seals on the New Zealand mainland by Polynesian subsistence hunting was in contrast to the sustainable harvest at Chatham Islands, 870 km east of South Island. Although Polynesians (Moriori) colonised Chatham Islands during or before the 16th Century (King 1989), fur seals were still numerous at the time of first contact with Europeans in 1791 (Richards 1982). Oral records of hunting fur seals (Richards

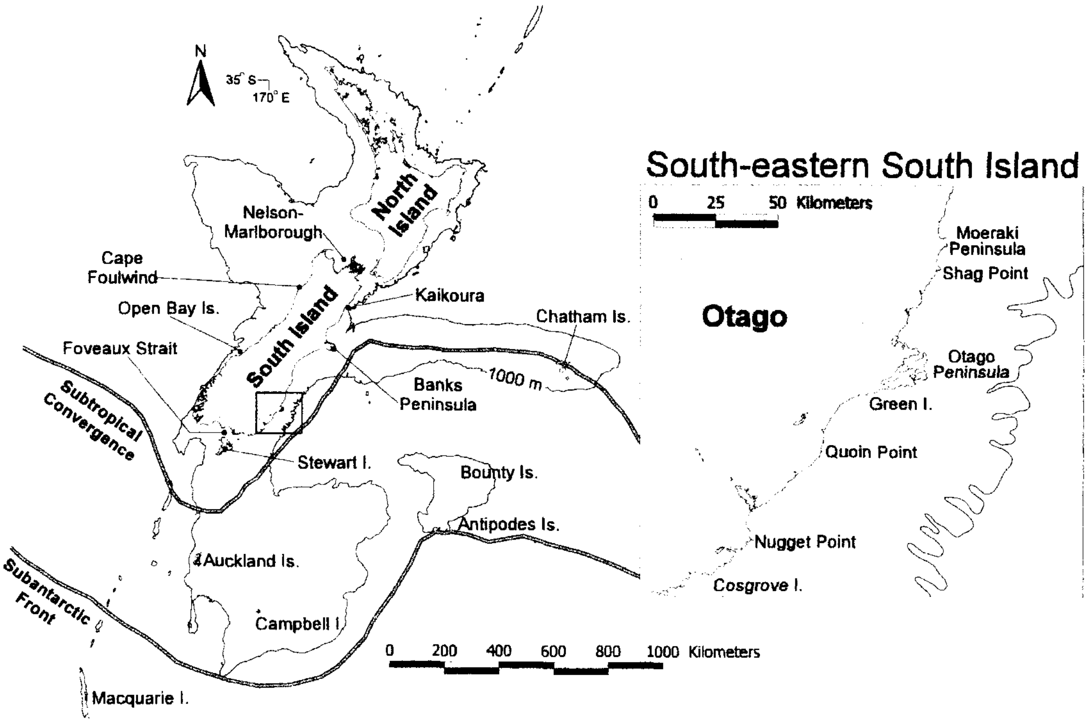

Fig. 1 Islands of the New Zealand region, including the Subtropical Convergence and the Subantarctic Front (after Heath 1981), the 1000-m isobath, and a detailed map of south-eastern South Island.

1982) match the archaeological evidence (Smith 1977; Sutton 1982): they were the most important source of food; large animals were targeted throughout the year even though pups were available; killed animals were removed intact from colonies before butchering; and permanent human settlements were adjacent to seal colonies. Also, sealskins were used for clothing (Richards 1982), a practice not reported from mainland New Zealand (Beattie 1994).

It appears therefore that the consumption of fur seals at Chatham Islands was sustainable. We suggest that this pattern resulted from one of two reasons. First, the human colonisation of Chatham Islands during or before the 16th Century (King 1989) was a relatively recent event, with perhaps insufficient time elapsed or a population too small to deplete the local fur seals. Second, the presence of many uninhabitable nearshore islands may have held a sufficient reservoir of seals to replace losses from human exploitation at readily-accessible sites (e.g., Hildebrandt & Jones 1992). In contrast, there were few uninhabitable nearshore islands around most of the New Zealand mainland. The notable exception was around Stewart Island, where fur seals remained numerous until the arrival of Europeans.

In conclusion, the near elimination of fur seals in mainland New Zealand was mainly due to Maori subsistence hunting. The misconception that the pristine distribution of fur seals was the same as that recorded by Europeans at the end of the 18th Century has been perpetuated in scientific reviews (e.g., Crawley & Wilson 1976; Wilson 1981; Crawley 1990) and Maori lore (e.g., Graham 1993). The lack of Maori oral history addressing fur seals as major source of food is probably because of the depletion of the fur seal population early in Maori history. This impact mirrored the consumptive depletion of seals by hunter-gatherer societies elsewhere. The local extirpation of seal populations in prehistoric times by subsistence hunting has been documented for indigenous peoples of the north Pacific (Yesner 1988; Hildebrandt & Jones 1992), southern South America (Lanata 1990), and southern Africa (Woodborne et al. 1995). The impact of human colonisation was not restricted to extirpation of seals but typically resulted in the demise of most large-bodied species (Diamond 1991; Flannery 1994).

Exploitation for sealskins

A period of intensive and unregulated commercial sealing by Europeans began in 1792 at south-western South Island, spread to offshore temperate and subantarctic islands after 1800, and almost ceased because of a lack of seals by the 1830s (Gaskin 1972; Richards 1982; Taylor 1982, 1992; Crawley 1990). Lalas & Bradshaw (1998) suggested that a constant arithmetic rate of change model would give a realistic interpretation of the annual rates of decrease in fur seal numbers because sealing effort was intense throughout this period; a 15% annual rate of decrease in the fur seal population would have resulted in their near extinction (to <2% of initial size) in 25 years, and a 10% rate would have achieved this in 35 years. Closed seasons and hunting permits were introduced from 1875 and the last commercial take of fur seals in the New Zealand region was in 1946 (Crawley 1990). All species of seals within the New Zealand 200 nautical mile Exclusive Economic Zone (EEZ) are now fully protected under the Marine Mammals Protection Act 1978.

As an outcome of the competitive secrecy in the sealing industry, the actual number of fur seals killed in the New Zealand region is unknown (Crawley 1990). However, this inaccuracy in records of numbers and locations extended beyond a desire to keep lucrative locations secret. Five other sources of unreliability in records are given by Richards (1982, 1994) and are summarised here: (1) port records are incomplete for the number of sealskins landed in Australia; (2) the Australian-based sealing industry was prohibited by law from operating in the southern New Zealand region after 1805 and so records were falsified; (3) American sealers also operated in the New Zealand region but their counts of sealskins could have included fur seals taken from South America; (4) catches by vessels lost at sea remain unknown; and (5) the ratios of fur seals killed to the number of sealskins reaching the market are unknown. Another source of unreliability is that some American vessels sealing in Australiasia probably did not enter local ports and hence there is no record of their catches in this region.

PATTERN OF RE-COLONISATION

Current trends in distribution and abundance

The distribution resulting from the present pattern of re-colonisation and recovery of New Zealand fur seals at islands south of New Zealand does not resemble the perceived pristine distribution and abundance of the species in this region (Table 1). Bounty Islands accounted for relatively few sealskins (Taylor 1982) but now hold the largest breeding population south of South Island (Table 1). Numbers at Bounty Islands, Antipodes Island, and Macquarie Island have shown long-term annual increases averaging c. 5% (Table 1). Survey results from Auckland Islands and Campbell Island are too imprecise to show population trends but numbers at Snares Islands appear to have stabilised following rapid increases through the 1950s and 1960s (Carey 1998).

Antipodes Island and Macquarie Island apparently lacked large breeding populations, but instead, they supported large numbers of seals termed "upland seals" by 19th Century sealers (Taylor 1992; Richards 1994). Both Taylor (1992) and Richards (1994) suggested that upland seals were juvenile New Zealand fur seals. If so, then the paucity of breeding New Zealand fur seals at both locations before the arrival of sealers was in marked contrast to that of this species elsewhere.

Macquarie Island has been included in the breeding distribution of New Zealand fur seals (e.g., Wilson 1981; Crawley 1990) from reports of pups born there since 1955 (Csordas 1958; Csordas & Ingham 1965). This breeding status was questioned and refuted during the 1980s because, although New Zealand fur seals were the most numerous fur seal species at Macquarie Island, they did not breed there (Shaughnessy & Fletcher 1987; Shaughnessy et al. 1988). Instead, the breeding reported by Csordas (1958) and Csordas & Ingham (1965) was attributed to two conspecifics, subantarctic fur seals (*A. tropicalis*) and Antarctic fur seals (*A. gazella*), with the former considered the most likely candidate for upland seals (Shaughnessy & Fletcher 1987). New Zealand fur seals have recently started breeding there but only sporadically and in small numbers (Shaughnessy & Goldsworthy 1993; Goldsworthy et al. 1998).

The main breeding locations for fur seals in the New Zealand region north of Bounty Islands according to Crawley (1990) were around Stewart Island, islands in Foveaux Strait, the Fiordland coastline at the south-western corner of South

Table 1 Minimum numbers of sealskins taken by 19th Century sealers, and published recent counts and population estimates for New Zealand fur seals at islands south of New Zealand.

Location (north to south)	Minimum take of sealskins		Most recent published count				Trend in seasonal peak of abundance (as assessed in source reference except for Macquarie I.)
	Source reference	Number	Source reference	Year of count	Pups	Juveniles and adults	
Bounty Is	Taylor (1982)	50 000	Taylor (1982)	1980	3280	6700	Total population calculated as 16 000: increase 1903–80 at average 5% p.a.
Snares Is	-	unknown	Carey (1998)	1984	179	1683	No detectable increase 1971–97
Antipodes I.	Richards (1994)	250 000	Taylor (1992)	1985	7	1747	Increase 1969–85 at average 4% p.a.
Auckland Is	-	unknown	Wilson (1974)	1972–73	min. 19	min. 230	Total population est. 1000, range 750–1500; data too imprecise to detect population trends
Campbell I.	Richards (1994)	140 000	Moore & Moffat (1990)	1987	min. 126	-	Probable increase; pup counts for key sites; no valid counts of juveniles and adults
Macquarie I.	Shaughnessy & Fletcher (1987)	193 000	Shaughnessy & Fletcher (1987)	1982	0	1222	Increase 1950–82 at average 6% p.a. calculated by Taylor (1992)

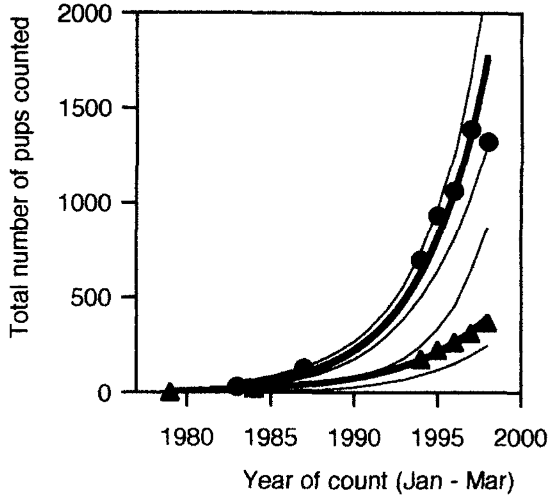

Fig. 2 Annual total numbers of pups of New Zealand fur seals counted (N_t) at Otago Peninsula (circles) and Nugget Point (triangles). Lines are exponential curves of best fit ±95%: Otago Peninsula $N_t = 35.5e^{0.26t}$ ($n = 7$, $r^2 = 0.982$, year $t_0 = 1983$); Nugget Point $N_t = 2.0e^{0.29t}$ ($n = 7$, $r^2 = 0.949$, year $t_0 = 1979$).

Island, and around Chatham Islands. The only record for breeding around South Island away from Fiordland and Foveaux Strait in 1973 was a few pups at Banks Peninsula (Wilson 1981). Since then, New Zealand fur seals have increased in number and spread northward. Breeding colonies are now scattered around South Island (Baird 1994; Lalas & Harcourt 1995; Taylor et al. 1995; Lalas & Murphy 1998) and breeding has spread to southern North Island (Dix 1993a).

Present temporal trends in breeding numbers vary around the South Island. The most extensive database exists for Open Bay Islands, where numbers stabilised by 1975 (Baird 1994). In contrast, pup numbers along the northern and the south-eastern coasts of the South Island have increased at c. 20–25% annually (Lalas & Harcourt 1995; Taylor et al. 1995; Lalas & Murphy 1998). The most recent estimates for exponential rates of population increase in pup numbers for south-eastern South Island were 0.26 (95% confidence interval 0.22–0.30) for colonies on Otago Peninsula (Bradshaw et al. 2000) and 0.29 (95% confidence interval 0.21–0.36) for Nugget Point (calculated from Lalas & Murphy 1998) (Fig. 2). These exponential (b) rates corresponded to average annual rates of increase (r, where $b = \ln(1 + r)$: Gerrodette 1987) of 30 and 33%, respectively.

In conclusion, the distribution resulting from the present pattern of re-colonisation of New Zealand fur seals does not resemble their perceived pristine distribution and abundance at islands south of New Zealand. We consider that a verification of the taxonomic status of upland seals would assist in resolving this anomaly. Before the arrival of 19th Century European sealers upland seals were abundant at Antipodes and Macquarie Islands, the only islands on or south of the Subantarctic Front (Fig. 1). Solitary subantarctic fur seals have been recorded to the east of Macquarie Island (Taylor 1990), indicating the possibility for an eastward spread of this species to islands near the Subantarctic Front. Recent population trends for New Zealand fur seals at the southern islands indicate much lower rates of increase than at northern and south-eastern South Island. We suggest that the pristine distribution of *A. forsteri* in the New Zealand region was temperate, with South Island as the population centre, rather than subantarctic. This hypothesis is testable with time: as fur seals continue to increase in number and spread the majority of the population should be found around South Island. In addition, since we know that fur seals once bred around the entire country (Smith 1989) and venture as far north as the tropical South Pacific (King 1976; Walter & Smith 1998), the breeding distribution of New Zealand fur seals can be expected to continue to expand northwards in mainland New Zealand (e.g., Dix 1993a; Taylor et al. 1995).

Methods used to estimate population size and trends

Population model

We assessed the credibility of reproductive parameters published for New Zealand fur seals by applying them in density-independent, deterministic simulations of the female population. We ran a spreadsheet construction of a Leslie matrix model (Leslie 1945; Burgman et al. 1993) for 100 years where the initial female population consisted solely of 100 first-time breeders. All simulations took no more than 60 years to attain a stable demography, as indicated by a maximum absolute difference of <0.0001 in the age class proportions between decades (Burgman et al. 1993).

For each simulation we calculated the average annual rate of change in population size (r), where N_t (population size in year t) = $N_{t-i}(1 + r)$, and the ratio of the total population (including pups) to pups. We used the following reproductive parameters: (1) 1:1 sex ratio at birth; (2) age at first breeding (years); (3) annual birth rate; (4) annual survival rate from birth to the end of the first year; and (5) annual survival rate of animals >1 year old. We ran four different simulations, with values for parameters from Crawley & Brown (1971) for Taumaka Island, Open Bay Islands; from Taylor (1982) for Bounty Islands; from Mattlin (1987), where values for Taumaka Island were taken as representative for the species; and from Wickens & York (1997) for the maximum value for each parameter among all *Arctocephalus* species.

The simulations applying values derived from Taumaka Island both produced untenable results (Table 2). Both sets of values generated large negative population growth rates, leading to the obvious conclusion that the value for at least one parameter was incorrect in each case. The simulation applying values used for Bounty Islands generated a population that was stable or increasing at 1% annually (Table 2). Although this is a feasible result, Taylor (1982) suggested that this population was increasing at c. 5% annually from 1903 to 1980, and c. 3% annually from 1980 to 1994 (Taylor 1996).

The simulation using the highest published values of reproductive parameters for females from all *Arctocephalus* species (Wickens & York 1997) produced a maximum annual population growth rate of 12–13% (Table 2). This rate was still inferior to that recorded for northern (Taylor et al. 1995) and south-eastern South Island (Fig. 2; Lalas & Harcourt 1995; Lalas & Murphy 1998; Bradshaw et al. 2000). The only source of population growth beyond the maximum intrinsic rate must be extrinsic, in the form of immigration. Indeed, immigration has been postulated as an important source of population growth for many breeding colonies in New Zealand (Taylor et al. 1995; Bradshaw et al. 1999a).

Counts of fur seals ashore

We found 15 published references where estimates for the total number of New Zealand fur seals in the New Zealand region were presented for the first time either for a new population estimate or for a particular period (Table 3). Various combinations of these references presented one estimate for the pristine population size, three for the period preceding European exploitation, and 13 for the period following the cessation of commercial sealing in 1946. Five references did not designate sources for their population estimates. The other 10 estimates were derived from one of three different sources: counts of animals ashore by R. A. Falla in the 1930s and 1940s (Falla 1953; Gaskin 1972), counts of animals ashore by G. J. Wilson in the 1970s (Crawley & Wilson 1976; Wilson 1981; Mattlin 1987; Crawley 1990; Taylor 1990; Baird 1994), and extrapolations from landed catches of sealskins by R. Richards (Richards 1994; Carey 1998).

The Wilson (1981) estimates for total and range in numbers of New Zealand fur seals in 1973 became the baseline figures for most of the recent estimates of population size in the New Zealand region (Table 3). His numbers were derived as the sum of counts or estimates of fur seals seen ashore. The presented ranges in numbers (Wilson 1981) were not statistical confidence intervals; rather, they were intended to convey the "reliability of counts" (Wilson 1981: 4). Counts of pups were not treated consistently: they were sometimes included in counts (e.g., Solander Islands; Wilson 1981: 25), and sometimes excluded (e.g., for Snares Islands from Crawley 1972). Regardless, single counts of fur seals ashore are highly variable (Eberhardt et al. 1979; Thompson et al. 1997) and might not produce reliable estimates of population size because counts vary according to the time of day and year, number of surveys, weather, sea conditions, visibility, and terrain (Stirling 1968; Crawley 1972; Miller 1975; Bradshaw et al. 1999a). In addition, the proportion of individuals at sea remains unknown (Eberhardt et al. 1979; Shaughnessy et al. 1994). We conclude that all estimates for total population size of New Zealand fur seals in the New Zealand region lack robustness because none has given any statistical indication of accuracy and precision.

Counts of pups offer the only definitive assessment of population size because young pups are the only age class that is restricted to land (Chapman & Johnson 1968; Taylor 1982; Shaughnessy et al. 1994, 1995; Lalas & Harcourt 1995; Taylor et al. 1995). However, this method relies on the assumption that the proportion of females that breed remains constant among years. Pup counts (Table 4) can indicate long-term trends if executed consistently but they are not equivalent to absolute pup numbers because some pups may die before the count and others are missed (Lalas & Harcourt 1995). Earlier census work targeting pups compensated for this undercounting with guesses or with extrapolation from other fur seal species (Crawley & Brown 1971; Taylor 1982). More recently, mark-recapture techniques have been applied to gain more reliable results (Lalas & Harcourt 1995; Taylor et al. 1995; Bradshaw et al. 1999b).

Population estimates extrapolated from counts of pups

Regional population estimates have been extrapolated from numbers of pups through the application of "multipliers" (i.e., constants applied to counts or estimates of pup numbers). Despite warnings that multipliers incorporate reproductive parameters of unknown accuracy (Shaughnessy et al. 1994) that vary with demography (Taylor 1996),

Table 2 Population parameters for *Arctocephalus forsteri* and results of four simulations with a Leslie matrix model.

	Taumaka I. Crawley & Brown (1971)	Bounty Is Taylor (1982)	Taumaka I. Mattlin (1987)	Highest productivity for *Arctocephalus* spp. Wicken & York (1997)
Age at first breeding (yr)	3	3	5	3
Annual birth rate	0.70	0.80	1.00	0.84
Annual survival 1st yr	0.40	0.76	0.61 (max. age 15 yr)	0.92
Annual survival >1 yr	0.70	0.84	0.77 (max. age 23 yr)	0.92
Population annual growth rate (*r*)				
with max. age 15 yr	−22%	0%	−28%	12%
with max. age 23 yr	−21%	1%	−10%	13%
Ratio total population : pups				
from source publication	4.20	4.90	–	–
from Leslie matrix model				
with max. age 15 yr	5.15	5.38	6.01	5.39
with max. age 23 yr	5.18	5.39	5.48	5.40

Table 3 Published estimates for the number of New Zealand fur seals in the New Zealand region, arranged in chronological order of the year of applicability for each estimate.

Source reference	Year for estimate (A.D.)	Estimate	Source of estimate
Carey (1998)	c. 1000	1.5–2 million	Richards (1994) figure
Anon. (1992)	c. 1800	up to 500 000	None given
Richards (1994)	c. 1800	1.5–2 million	Extrapolated from figures for catches by 19th Century sealers
Anon. (1995)	c. 1800	c. 1.5 million	Anon. (1995) total given for 1995 was 5% of total in 1800
Falla (1969)	1948	up to 20 000	Sum from estimates for all areas; dates 1934–48
Falla (1953)	1949	considerably <50 000	None given
Gaskin (1972)	c. 1970	20 600	Described as a combination of local censuses
Crawley & Wilson (1976)	? 1973	40 000	Sum from censuses for all areas; dates 1950?–74?
Wilson (1981)	1973	39 000, range 30 000–50 000	Sum from censuses for all areas; dates 1950–74
Mattlin (1987)	1984	c. 50 000	Wilson (1981) figure increased to account for Taylor (1982)
Crawley (1990)	1986	probably >55 000	Wilson (1981) figure adjusted for increases since 1973
Taylor (1990)	1990	perhaps nearer 100 000	>55 000 in Crawley (1990) was considered too low
Talley (1991)	1991	60 000	None given
Baird (1994)	1994	56 000–79 000	Included (mainly unpublished) estimates since Wilson (1981)
Anon. (1995)	1995	<80 000	None given
Barton (1996)	1996	c. 100 000	None given

no one has yet questioned their use. Crawley & Brown (1971) and Taylor (1982) produced multipliers of 4.2 and 4.9, respectively, for New Zealand fur seals. The latter has been applied to not only this species in the New Zealand region (Taylor 1982, 1996; Lalas & Harcourt 1995; Taylor et al. 1995) and Australia (Shaughnessy et al. 1994; Shaughnessy et al. 1995, 1996), but also to other *Arctocephalus* species (Goldsworthy et al. 1998). Two reasons for caution in the general application of a multiplier can be deduced from Table 2. First, the published multipliers differ from those calculated from the respective Leslie matrices using the same data. Second, the multipliers calculated from the Leslie matrices varied inversely with population growth rate; the multiplier will therefore differ among local populations having different growth rates.

Consequently, estimates for the total number of fur seals in New Zealand have become a confused mixture of direct counts and estimates from Wilson (1981), interdigitated with localised updates derived from pup counts. Although we are stating that all estimates for current population size are inaccurate, we must emphasise that we are not questioning the importance of published data. The published accounts of temporal and geographical trends in the breeding status of colonies are fundamental to the understanding of fur seal distribution and abundance.

ENVIRONMENTAL CONSEQUENCES OF RE-COLONISATION

With an increasing population of fur seals in New Zealand, both in terms of number and distribution, the interactions between fur seals, their marine and terrestrial environments, and humans have increased and can be expected to continue to increase. In the following sections we describe these interactions and examine the credibility of current claims and perceptions.

Interactions with fisheries

Types of interactions between fur seals and fisheries

Interactions between fur seals and fisheries were assessed for South Africa by Wickens et al. (1992b) and defined as either "biological", involving potential competition for the same fish stocks or "operational", involving direct encounters during fishing operations. Operational interactions can be

Table 4 Comparisons of counts of New Zealand fur seals ashore at south-eastern South Island, New Zealand, for 1973, before breeding began, and 1995–98. Entries for 1995–98 are for years with counts done in January or February by C. Lalas in association with published accounts in Lalas & Harcourt (1995), Lalas & Murphy (1998), and Bradshaw et al. (2000). (– = no survey; the entry for coast west of Cosgrove Island was from January 1994 in Lalas & Murphy (1998).)

Location	1995		1997		1998		Averages of counts (1995–98)			Estimates by Wilson (1981) for Jan–Feb 1973	
(north to south)	Pups	Juveniles and adults	Pups	Juveniles and adults	Pups	Juveniles and adults	No. counts	Pups	Juveniles and adults	Total	Range
Moeraki Peninsula	24	828	28	907	45	807	3	32	847	*	0–6
Shag Point	0	187	0	111	0	164	3	0	154	*	0–8
Otago Peninsula	931	6551	1385	6978	1322	4809	3	1213	6113	905	820–990
Green I.	0	154	–	–	–	–	1	0	154 }	50	30–100
Quoin Point	0	30	0	64	–	–	2	0	47 }		
Nugget Point	222	1220	310	1069	367	904	3	300	1064	6	5–8
south to Cosgrove I.	0	733	0	856	2	538	3	1	709 }	*	*
west of Cosgrove I.	–	–	–	–	–	–	1	0	135 }		
Totals for south-eastern South I.								1593	9223	950	850–1100

* Not quantified by Wilson (1981): indicative of small numbers.

detrimental to fisheries when seals eat fish that have been caught in fishing gear, damage gear, or disrupt operations. Reciprocally, operational interactions are detrimental to seals when seals drown in nets (incidental kills) (e.g., Gibson 1995; Miller et al. 1996), are killed deliberately (e.g., Gulland 1987; Newstrack 1998), or are entangled in fishing debris (Bonner 1982; Shaughnessy 1985; Croxall et al. 1990b; Wickens et al. 1992a; Arnould & Croxall 1995; Slooten & Dawson 1995; Walker et al. 1997).

The spectrum of interactions and perceived conflicts between fur seals and fisheries has not been assessed for the New Zealand region. Here we follow chronologically the key events in regulation and research and the changes in human attitude towards New Zealand fur seals through this century. We also discuss these attitudes and perceptions in light of the current understanding of the interactions between pinnipeds and global commercial fisheries.

Seals eat fish: the 1946 open season

An increase in numbers of New Zealand fur seals around Foveaux Strait prompted complaints in 1945 from commercial fishers targeting blue cod (*Parapercis colias*) (Sorensen 1969b). The government response was encapsulated in this quote from a memorandum dated 2 August 1945 from the Chief of Fisheries to the Acting Secretary of Marine Department: "It seems to be the general opinion and complaint among Bluff and Stewart Island fishermen that the seal population on their fishing grounds has considerably increased of recent years. From this it follows that the killing of seals would be helpful to fish supplies" (Sorensen 1969b: 7). The outcome was an open season restricted to southern New Zealand in 1946 with a tally of 6187 seals killed under licence and their skins marketed (Sorensen 1969b). The kill was indiscriminate with no restrictions imposed on species, sex, or size of seals (Sorensen 1969b).

The 1946 open season was the last legal cull or harvest of fur seals in the New Zealand region. The motivation for this open season remains clouded as a mix of the desire to eliminate competition with fisheries and to profit from commercial exploitation for sealskins (Sorensen 1969b). Not only were no blue cod found in the stomach contents of killed seals (Rapson 1969) but also the expected profit from the marketing of sealskins failed to materialise (Sorensen 1969b). Rapson (1969) even suggested that the perceived reduction in commercial catches was in fact attributable to a lack of freezer space for blue cod awaiting transport to market. Falla (1969: 73) aired a conservationist voice in 1948 with his recommendations following the 1946 open season by stating that "the fur seals of New Zealand seas are an integral part of the marine fauna". However, he was not against their commercial exploitation providing this was sustainable and profitable, an opinion he repeated (Falla 1962). The most recent coherent call for a resumption of commercial sealing appears to have been in 1962 by the fishing industry in a report that accepted that seals caused only negligible damage to fisheries (Sorensen 1969a). With the exception of occasional complaints by fishers (Sorensen 1969a), New Zealand fur seals did not reappear in the public limelight until 1989.

Incidental kills in trawl fisheries

A winter trawl fishery targeting hoki (*Macruronus novaezelandiae*) off the western coast of South Island began in the early 1970s, peaked in the late 1980s, and has since stabilised as hoki fisheries elsewhere became important (Annala & Sullivan 1998). Public awareness of the incidental kills of New Zealand fur seals in this fishery was first aroused by an article in the conservationist magazine *Forest & Bird* in 1989 (Hutching 1989). In the following year the fishing industry responded to conservationist concerns with a Code of Practice issued by the New Zealand Fishing Industry Association to vessel captains (Baird 1994; Gibson 1995). This document described fishing strategies designed to minimise seal kills; however, the effectiveness of this management action still remains untested (Slooten & Dawson 1995).

The Marine Mammal Protection Act 1978 made it a legal requirement for fishing vessels to report any capture of fur seals within the New Zealand EEZ. However, quantifying this incidental catch is difficult since captures are rarely reported voluntarily (Gibson 1995; Slooten & Dawson 1995). Interactions between fisheries and fur seals have been assessed in a series of reports from the Ministry of Fisheries (Mattlin 1994; Baird 1994, 1995, 1996; Gibson 1995). In the most comprehensive report, Gibson (1995) produced estimated means of 456 to 1426 fur seals killed in trawl nets annually in the New Zealand EEZ from 1990 to 1993. Although most were caught in the hoki fishery off the western coast of South Island, incidental catches of fur seals were widespread and occurred in all offshore trawl fisheries in the EEZ (Gibson 1995).

We consider calls for the closure of fishing grounds in areas of high fur seal density (e.g., Slooten & Dawson 1995) to be inappropriate. Although much remains unknown about the population biology of New Zealand fur seals, the high rates of increase estimated for some South Island locations indicate that species viability overall is not at immediate risk. Removal of this option, at least in the short term, avoids the negative financial implications to the fishing industry. However, we support efforts to minimise the incidental kills of fur seals through the fisheries codes of practice (Gibson 1995).

Recent polarised attitudes

A polarisation of attitudes followed publicity of kills of New Zealand fur seals in trawl fisheries in 1989. The extremes were encapsulated in the publication of opinions of a member of the fishing industry (Talley 1991) and a member of *Greenpeace* (Duncan 1991) by the magazine *New Zealand Professional Fisherman* in 1991. Talley (1991) suggested that seals were increasing rapidly in number and had voracious appetites. He suggested that an unchecked increase would threaten fisheries so that culling would become an inevitable necessity. Duncan (1991) suggested there was no evidence that seals were increasing in number or becoming a threat to the environment. He suggested that the preferred prey of seals were non-commercial species and that fisheries themselves were the main threat to fish stocks and the environment. Basic arguments appear unaltered in the most recent exchange in the magazine *Seafood New Zealand*. Stevens (1999) suggested that culling would become inevitable because fur seal numbers were increasing rapidly, with consequent detrimental impacts ashore and at sea. Donoghue (1999) responded that non-commercial species predominate in the fur seal diet and that there was no strong evidence for population growth. We conclude that the opposing extremes, preservation versus culling, appear irreconcilable.

Worldwide pinniped-fisheries interactions

The perceived conflict between fur seals and fisheries in New Zealand is symptomatic of a worldwide attitude that seals and fisheries are competitors for the same fish resources. This attitude perpetuates the misbelief that culls of fur seals would reduce competition because fewer seals would eat fewer fish, and the surfeit of fish would become available for commercial exploitation (Bonner 1982; Butterworth et al. 1988; Harwood & Croxall 1988; Crawford et al. 1992; Lavigne 1992; Meÿer et al. 1992; Wickens et al. 1992a,b; Bowen 1997; Trites 1997). Although fur seals are conspicuous as top predators, their impact on fish stocks has been overemphasised (David 1987; Crawford et al. 1992; Harwood 1992; Lavigne 1992; Wickens et al. 1992b). Instead, the bulk of fish mortality is attributable to other predatory fish and the impact of marine mammals is relatively low (DeMaster & Sisson 1992; Wickens et al. 1992b; Trites et al. 1997). Consequently, an extermination of seals could result in only a negligible increase in fish available for commercial fisheries (Harwood & Croxall 1988; Wickens et al. 1992b; Lalas & Bradshaw 1998). There are no known cases where a reduction in the abundance of marine seals has benefited fisheries catches (Butterworth et al. 1988; Lavigne 1992; Trites 1997). Instead, Lavigne (1992) and Meisenheimer (1995) suggested that a human paranoia towards predators has turned seals into scapegoats as competitors for fish stocks.

Operational interactions

Today there are some operational interactions in New Zealand between fur seals and offshore trawl fisheries and coastal salmon farms. Operational interactions in trawl fisheries have been quantified only for South Africa where consumption by South African fur seals (*A. pusillus pusillus*) equates to c. 0.2% of the value of the catch, and accounts for only c. 0.1% of the total consumption by fur seals (Wickens et al. 1992b). By comparison, the amount of all fish species caught that are discarded in New Zealand trawl fisheries targeting hoki has been estimated to be 30% of the landed hoki catch (Alverson et al. 1994). About 200 000 t of hoki are landed annually (Annala & Sullivan 1998). Consequently, we deduce that although operational losses to New Zealand fur seals remain unknown, they are small compared to amounts discarded by trawl fisheries.

Diet of New Zealand fur seals

New Zealand fur seals typically forage at night offshore over the edge of the continental shelf and over the continental slope (Harcourt et al. 1995; Harcourt & Davis 1997; Mattlin et al. 1998; Fea et al. 1999). Current knowledge of their diet stems from six studies that have highlighted the spatial and seasonal differences around the South Island (Street 1964; Rapson 1969; Tate 1981; Carey 1992; Dix 1993b; Fea et al. 1999). With the exception of benthic octopus species, the major contributors to prey biomass were pelagic, schooling species targeted by commercial fisheries: arrow squid (*Nototodarus sloanii*), barracouta (*Thyrsites atun*), hoki, and jack mackerel (*Trachurus* spp.).

The fact that New Zealand fur seals target commercial species is not accepted universally. Contrary opinions can be traced to three sources. First, Street (1964) stated that the main prey, octopus, arrow squid, and barracouta, were not of commercial interest. However, arrow squid and barracouta have since become important commercial species (Annala & Sullivan 1998). Second, Carey (1992) concluded that small, non-commercial fish species were targeted. However, although small fish predominated numerically in recent studies, they contributed only a small proportion towards the total prey biomass (Fea et al. 1999). Third, unsubstantiated anecdotal observations have been taken as indicative of fur seals targeting species of no or low commercial importance, for example frostfish (*Lepidopus caudatus*) in Duncan (1991).

Consumption rates and competition for fish stocks

The food requirements of free-living New Zealand fur seals remain unknown but are expected to fall within the range of other similar-sized fur seal species (Trites et al. 1997; Best 1998). Estimates for prey consumption rates expressed as percentage of body mass consumed daily by fur seal species range from 3 to 13% for populations (Innes et al. 1987; Wickens & York 1997). Trites et al. (1997) applied a mean body mass of 32.3 kg, derived for New Zealand fur seals by Trites & Pauly (1998), to an equation for consumption rate by Innes et al. (1987) to deduce that mean daily intake of individuals was 1.61 kg, equivalent to 5% of mean body mass.

Valid quantified assessments of competition between seals and fisheries involve a comparison of the estimates of population size and consumption rate of seals, catches by fisheries, and the biomass of fish stocks. This competition has been assessed for seals in the Pacific Ocean by Trites et al. (1997). For New Zealand fur seals in the New Zealand region, they applied their calculation for daily intake to a population size of 40 000, the Wilson (1981) figure. This produced a figure of c. 23 500 t of prey consumed annually. Trites et al. (1997) recorded <20% overlap in prey composition between seals and fisheries in the south-western Pacific encompassing New Zealand, a percentage only one-third the 60% overlap estimated for the entire Pacific region. Diet for New Zealand fur seals was taken from categorisations of prey types by Pauly et al. (1998), who used Street (1964) and Carey (1992) as primary sources.

Clearly, the accuracy of estimates for the population size and diet of New Zealand fur seals both impact on the reliability of assessments of interactions with fisheries.

Deliberate legal kills and the potential for harvesting

New Zealand fur seals typically forage offshore, a pattern that has largely avoided overlap and conflict with recreational fisheries (Fea et al. 1999) and inshore commercial fisheries. However, some individuals have been observed foraging near shore (Sorensen 1969a), and fur seals occasionally take fish from recreational set nets and fishing lines (Lalas pers. obs.). The targeting of coastal salmon farms has raised particular concerns. Here, individual fur seals can learn to take advantage of untraditional food sources and cause problems for local enterprises (Department of Conservation 1997).

A precedent for a legalised kill of New Zealand fur seals was set in 1997 with a permit issued under the Marine Mammals Protection Act 1978 to a company that operated salmon farms (Department of Conservation 1997). This permit set a prerequisite that structures were to be installed to minimise seal access into coastal salmon cages. A protocol was set to deal with any seal that gained entry, and this could culminate in the seal being killed by Department of Conservation staff. To date, this clause of the permit has been implemented once, with two fur seals shot in July 1998 (Newstrack 1998). Although the policy of killing problem individuals might appear extreme, it circumvents pressure for the implementation of a broader cull that would not necessarily eliminate the individuals responsible (Gulland 1987).

Beyond removing problem individuals (Gulland 1987), wholesale culls of New Zealand fur seals in attempt to improve commercial fish stocks (e.g., Talley 1991; Stevens 1999) are unlikely to benefit fisheries catches (see above). Therefore, implementing such culls would not be economically feasible without a commercial incentive. Much of the commercial incentive for the harvesting of seals disappeared in 1983 with the collapse of the international market for seal pelts (Butterworth et al. 1988; Harwood 1992). Consequently, this option appears defunct and can be dismissed without the need to consider the ethical implications. However, a lucrative market remains for seal penises as aphrodisiacs in Asian apothecary (Bräutigam & Thomsen 1993; Malik et al. 1997).

There is also the feasibility of initiating local harvests of seals for food under the umbrella of *te tikanga Maori o mahinga kai*, the "customary use of wildlife by Maori" (Moller 1996: 90). This term encompasses all aspects of traditional food harvest and management by the indigenous people of New Zealand including conceptual and historical aspects (Anderson 1996), legislative implications (Crengle 1997), and practical applications (Dacker 1990; Moller 1996). Ngai Tahu, whose tribal territory encompasses nearly all South Island and all Stewart Island (Anderson 1996), have claimed propriety rights for seal fisheries (Waitangi Tribunal 1992: 80) but have not expressed an interest in renewing the status of fur seals as *mahinga kai* (Garven et al. 1997). Moller (1996) stated that there seemed to be no scientific basis against a sustainable harvest of fur seals in New Zealand. However, calls for traditional harvest are met with indignation by people who regard the killing of native species as unethical (Gulland 1987; David 1995; Moller 1996). The present rates of population increase at some colonies suggest that they could sustain additional mortality. We must stress, however, that implementing an indigenous harvest should not be used as an excuse for culling or commercial harvest.

Impacts ashore

Coastal vegetation

New Zealand fur seals are colonial ashore and select rocky coastlines to rest and breed. They can spread inland, resulting in the death of coastal vegetation (Crawley & Wilson 1976). For example, as a consequence of the depletion of fur seals by sealers, vegetation spread at Open Bay Islands (Burrows 1972). Applying this example, Crawley & Wilson (1976) suggested that clearance of vegetation could become a widespread feature with a larger fur seal population.

There is some evidence for this prediction in south-eastern South Island. We have observed only one case where the native vegetation has been completely destroyed by the presence of fur seals, at Te Pari o Te Mataahua (45°48′S, 170°45′E), Otago Peninsula. Here, the total available area of c. 0.1 ha was denuded by fur seals between 1985 and 1995. Given the high rates of increase of fur seals we had expected to find more instances of vegetation clearance. To date the typical impact at Otago has been the complete clearance of blue shore tussock (*Poa astonii*) and the breaking of branches from the shrub, *Hebe elliptica*, resulting in a clearance of vegetation at ground level but leaving the canopy intact.

Although the damage caused by the presence of seals and seabirds can impact detrimentally on woody vegetation, it can promote the establishment and persistence of herbaceous plant communities. For example, the reduction of fur seal populations is believed to have been partly responsible for the extirpation of some species of *Lepidium*, including the endangered Cook's scurvy grass (*L. oleraceum*), from much of the New Zealand coastline (Garnock-Jones & Norton 1995; Norton et al. 1997). Similarly, the "megaherb" coastal communities characteristic of New Zealand's temperate and subantarctic islands are frequently associated with, and resilient to, disturbance by seals (Meurk et al. 1994).

In conclusion, the potential effects of an increasing fur seal population on terrestrial habitat can be categorised as both negative and positive. The resulting changes in the plant communities from fur seal colonisation have been observed elsewhere. Antarctic fur seals have been responsible for trampling fragile mosses and lichens as well as the eutrophication of lakes in subantarctic islands (Smith 1988; Ellis-Evans 1990; Hodgson et al. 1998). On the other hand, the dependence of some coastal plants on the mechanical disturbance of soil, seed dispersal, and nutrient provisioning by seals is a positive side effect of re-colonisation (Meurk et al. 1994; Norton et al. 1997).

Seabird habitat

Mechanical damage to soil and vegetation by the presence of fur seals could also impact on nesting seabirds. To date the only published record of a possible negative impact from the New Zealand region is for burrow-nesting sooty shearwaters (*Puffinus griseus*) at Nugget Point (Hamilton 1993). In contrast, crevice-nesting blue penguins (*Eudyptula minor*) appear to be unaffected by seals and were present at 12 of the 29 fur seal breeding colonies at Otago Peninsula in our 1998 census. Fur seals can also displace seabirds ashore by reducing the area available for breeding (Bonner 1985; Croxall et al. 1990a; Crawford & Payne 1995).

Also, is there little evidence for marine-based interactions between fur seals and seabirds, either in the form of competition for prey (Butterworth et al. 1988; Crawford & Payne 1995), or of direct predation. Although fur seal predation of rock-hopper penguins (*Eudyptes chrysocome*) (Bailey & Sorensen 1962) and blue penguins (Notman 1985; Dix 1993b) has been reported in the New Zealand region, blue penguins are increasing at Otago Peninsula (Perriman 1997) despite large increases in the fur seal population there. This suggests that fur seal predation is not detrimental to their distribution or numbers. There is no other evidence to suggest that New Zealand fur seals are a source of mortality for other seabirds in New Zealand.

Direct interactions with people

Tourism

Falla (1969: 73) predicted in 1946 that the consideration of fur seals as "natural resources" would shift from consumptive to non-consumptive exploitation as New Zealand's attitude towards tourism matured. This indeed turned out to be the case but tourism operations were unrestricted until the Marine Mammals Protection Regulations 1992 were established to prevent any potentially adverse effects of public viewing or interacting with marine mammals. All commercial operations that organise tourists viewing marine mammals in New Zealand must now hold a permit issued by the Department of Conservation. Human disturbance may inhibit the establishment of new breeding colonies (Taylor et al. 1995), and care is needed to ensure that tourism operations do not inadvertently disturb fur seals.

As an example for southern New Zealand, five tourism operators held permits to view or to swim with fur seals at Fiordland in 1995 with an expected annual patronage of up to 300 000 people (Department of Conservation 1995). In 1998 there were seven operators licensed in Otago (A. Pillai pers. comm.), and there are seal viewing or swimming operations at Kaikoura (Slooten & Dawson 1995), Cape Foulwind, and Nelson-Marlborough. However, the effects of tourism on New Zealand fur seals appear to be a low priority compared to other marine mammals, with the only reference to their potential disturbance restricted to their intolerance of close approaches by humans ashore (Department of Conservation 1995). The possible increase in disturbance to fur seals from tourism should continue to be monitored, and tourism operators should meet the cost of long-term monitoring to detect and avoid any detrimental impacts of their operations (Department of Conservation 1995; Slooten & Dawson 1995).

Potential conflicts ashore

As the New Zealand fur seal population continues to increase there is the potential for more direct interactions with human activities. Many fur seal colonies are adjacent to livestock pasture. As the density of fur seals at such sites continues to increase, there is the potential for some individuals to haul out on pastures and among livestock. We have begun to see examples of this phenomenon in south-eastern South Island, although the occurrence is rare. Since 1990 fur seals ashore at Pipikaretu Point (45°48′S, 170°45′E), Otago Peninsula, venture up to 100 m inland and have killed c. 1 ha of pasture grass. Since 1995 fur seals have also hauled out on pasture at Papanui Beach (45°52′S, 170°44′E), Otago Peninsula, and on the mainland adjacent to Cosgrove Island. In addition, territorial males may obstruct access to certain areas of coastline or pose physical threats to humans who wander into colonies. This has been observed during some summers (December and January) from 1990 at the Mole (45°47′S, 170°43′E), Pilots Beach (45°47′S, 170°44′E), and Puddingstone Rock (45°53′S, 170°45′E), Otago Peninsula.

Seals are hosts to a variety of infections, some of which are pathogenic to humans (Cawthorn 1994). Seal, or "spekk", finger is a bacterial infection formerly common among handlers of seals or seal meat (Cawthorn 1994). It is rare in New Zealand and to date has been restricted to biologists working with fur seals (Cawthorn 1994). Potentially zoonotic mycobacteria causing tuberculosis have been isolated from New Zealand fur seals in New Zealand (Hunter et al. 1998). Although humans have contracted tuberculosis from handling seals in Australia and Argentina (Forshaw & Phelps 1991; Woods et al. 1995; Bernardelli et al. 1996; Hunter et al. 1998), there have been no confirmed cases of transmission to humans in New Zealand. With the expected increases in interactions between fur seals and humans it will be interesting to note whether zoonoses could become a potential threat to humans in frequent contact with seals.

We suggest that direct fur seal-human conflicts onshore could be reduced through fencing strips of coastline if large numbers of seals spread into rural or urban areas. Also, the risk of transfer of zoonotic infections to humans could be minimised through public education and the appropriate precautions taken by humans in direct contact with seals (Hunter et al. 1998). An emphasis on the risk of contracting tuberculosis should discourage the public from approaching or handling fur seals.

RESEARCH PRIORITIES

The re-colonisation of fur seals at the scale of mainland New Zealand represents a rare opportunity for ecological research. The theoretical processes of population expansion and recovery can be tested in a natural experiment (Bowen 1997), and researchers have already begun to examine some of the processes and implications of re-colonisation (e.g., Taylor et al. 1995; Bradshaw et al. 1998, 1999a,b, 2000). This information is not only useful for testing purely empirical and theoretical science, it also provides information for the management of other species in comparable situations. However, to understand these processes it is essential to maintain the monitoring of annual pup production, survival, migration, and foraging behaviour in a number of areas around New Zealand (Bradshaw et al. 1999b). Temporal replication of regional census data is important to quantify trends and the extent to which fur seals are likely to impact on human commercial and recreational activities.

We suggest that accurate estimates of population size and the maximum allowable fisheries-related mortality (e.g., Wade 1998) cannot be expected until the following three databases are constructed: (1) Pup numbers—counts of pups at all main breeding colonies would indicate trends in distribution and abundance. However, estimates for the absolute numbers of pups can only be deduced from mark-recapture experiments that compensate for mortality and for pups missed in counts. (2) Parameters for population models—accurate estimates for survival rates, pregnancy rates, and age at first breeding are pre-requisites for the calculation of valid multipliers to estimate population sizes from pup numbers. Values for reproductive parameters need to be deduced through several years to minimise the potential impact of unrepresentative seasons; e.g., the untenable values from Mattlin (1987) are likely to have been derived from an anomalous year.

Multipliers to estimate population sizes from pup numbers can be expected to vary with the demography of breeding colonies (Wickens et al. 1992a). Consequently, the application of a single multiplier is unlikely to provide an accurate estimate of total population size. (3) Philopatry and site fidelity—quantification of dispersal and migration is required to estimate rates of population expansion (Bradshaw et al. 1999a,b, 2000).

CONCLUSIONS

In this review we have shown anomalies in the understanding of the distribution and abundance, interactions with humans, and impacts on the marine and coastal environments of New Zealand fur seals in the New Zealand region. All estimates for the present total population size are either unreliable or speculative. Fur seals have already spread beyond their distribution of 200 years ago and any prediction of their future abundance is speculation. Recently, there has been a shift in management science from the estimation of population size to the estimation of reproductive parameters because they are more robust and suffer from fewer assumptions (Lebreton et al. 1992). This approach can accurately define trends but still will not indicate absolute population size.

The most controversial issue involving New Zealand fur seals is their interaction with commercial fisheries. Here the New Zealand fishing industry is attempting to reduce the numbers of fur seals killed in trawl nets and is funding research via the annual Conservation Service Levy. We have shown that although the total population size remains unknown, the viability of fur seals in the New Zealand region is not at immediate risk. At the other extreme, nowhere in the world have seal culls been shown to improve fisheries catches. We therefore recommend that "no change" to present policy is the most sound course of action, at least until such time that fur seal reproductive parameters have been estimated reliably. A conclusion to remain passive in the management of this species would be a positive decision and not management by benign neglect. Our management proposal lies midway between the irreconcilable extremes of preservation and culling. However, it is not a compromise because it is unlikely to gain consensus from either faction. This impasse can only be resolved through continued debate enhanced by the publication of research on this species.

Understanding the re-colonisation processes of a depleted native species is indeed a rare opportunity in New Zealand. Not only can we gain important information on the myriad of unknowns regarding the perceived and real interactions between fur seals and humans, we can also begin to develop conceptual models that expand our understanding of large-animal population processes. This natural experiment should be supported by government, and perhaps funds such as the Conservation Service Levy (Clement & Associates 1997a,b; Department of Conservation 1998) can be used for the appropriate monitoring and research programmes recommended in this review.

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