# OBSERVATIONS OF MORTALITY OF FUR SEALS BETWEEN 1998 AND 2005 IN TASMANIA, AUSTRALIA

by R. Gales, A. V. Lee, D. Pemberton, A. Terauds and A. Irvine

(with two text-figures, one plate and four tables)

**Gales, R., Lee, A.V., Pemberton, D., Terauds, A. & Irvine, A.** 2010 (30:xi): Observations of mortality of fur seals between 1998 and 2005 in Tasmania, Australia. *Papers and Proceedings of the Royal Society of Tasmania* 144: 29–35. https://doi.org/10.26749/rstpp.144.29 ISSN 0080-4703. Biodiversity Conservation Branch, Department of Primary Industries, Parks, Water and Environment, PO Box 44, Hobart, Tasmania 7001, Australia (RG, DL, DP*, AI) Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, South Africa (AT, current address). *Author for correspondence. Email: David.Pemberton@dpipwe.tas.gov.au

Because of their often close relationship with the human environment, the deaths of marine mammals are often documented, particularly if there are links to anthropogenic influences. Between 1998 and 2005 a total of 504 dead Australian Fur Seals, *Arctocephalus pusillus doriferus*, and New Zealand Fur Seals, *Arctocephalus forsteri*, were reported in Tasmanian waters. Ninety individuals (18%) were dependent unweaned pups that had been displaced from their natal colonies. Of the 209 adult or subadult seals for which the cause of death could be ascertained, anthropogenic activities were identified as being responsible for the deaths of 172 individuals (82%), with 112 (53%) associated with fish farms. Most fish farm-related deaths occurred during the winter when adult and subadult seals were away from breeding colonies and seal numbers are highest around farms. The next most common cause of death was from firearms (41 individuals – 20%). Death of adults and subadults by natural causes accounted for 37 animals, or 18% of all deaths for which the cause was identified. Excluding pups, most seals were identified as Australian (80%) or New Zealand fur seals (3%). The remainder (17%) were identified as fur seals but not to species. Males were most common (58%), with only 6% identified as females; the sex of 36% could not be determined. Of the males, 106 (26%) were adults and 98 (24%) were subadults or juveniles.

**Key Words: fur seals, mortality, fish farms, shot, Tasmania, Australian Fur Seals, New Zealand Fur Seals, *Arctocephalus pusillus doriferus*, *Arctocephalus forsteri*.**

## INTRODUCTION

Both Australian Fur Seals, *Arctocephalus pusillus doriferus* Jones, 1925 and New Zealand Fur Seals *Arctocephalus forsteri* Lesson, 1828, occur in Tasmanian waters. Australian Fur Seals breed in nine main breeding colonies in Bass Strait with five of these in Tasmanian waters and four in Victorian waters (Pemberton & Kirkwood 1994, Arnould & Littnan 2000, Shaughnessy *et al.* 2000, 2002). Annual pup production is estimated to be around 19 000 pups with a total population estimate of approximately 92 000 individuals (Pemberton & Gales 2004, Kirkwood *et al.* 2005). Satellite-tracking studies and resights of marked animals have shown that the foraging range of Australian Fur Seals from both Tasmanian and Victorian waters extends around the Tasmanian coastline (Kirkwood *et al.* 2002, Robinson *et al.* 2008a). Australian Fur Seals are listed as a protected marine species under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act 1999).

New Zealand Fur Seals breed in much smaller numbers in Tasmanian waters with between 250 and 300 pups born each year in the southern part of the state, about 30 pups on the east coast and 10 pups in Bass Strait. The total population estimate in Tasmania is unknown because animals migrate from breeding colonies in other states and probably from New Zealand, but estimates of individual seals range between 1000 and 2000 individuals (DPIPWE unpubl. data). As for the Australian Fur Seal, satellite-tracking studies and observations of marked seals suggest that the range of subadult New Zealand Fur Seals from other breeding colonies (primarily those in South Australia) also extends into Tasmanian waters (Page *et al.* 2006). New Zealand Fur Seals are listed under Tasmanian threatened species legislation as rare (*Threatened Species Protection Act*, 1995) as well as being listed as a protected marine species under the EPBC Act 1999. Both Australian Fur Seals and New Zealand Fur Seals are "Specially Protected Wildlife" under the Tasmanian *Wildlife Regulations* (1999) and it is an offence to take (i.e., kill, shoot, catch or injure) either of these species unless authorised by a permit.

Although an increase in breeding numbers of Australian Fur Seals has been documented at several Victorian colonies (Arnould & Littnan 2000, Shaughnessy *et al.* 2000, 2002), Tasmanian breeding colonies appear to have been relatively stable over the past 10 years (Pemberton & Gales 2004). Current estimates of both Australian and New Zealand fur seals are significantly lower than estimates of pre-sealing numbers (Ling 1999, Arnould *et al.* 2003).

The ubiquitous presence of fur seals in Tasmanian waters has resulted in well documented interactions with humans in the marine environment, including the aquaculture industry (Pemberton & Shaughnessy 1993, Hume *et al.* 2002, Kemper *et al.* 2003). These interactions have the potential to impact on the efficiency of fishing operations and also have the potential to harm seals through entanglement and drowning in fishing gear. Furthermore, anecdotal reports suggest that seals are killed by some fishers in the belief that they can reduce the negative impacts on their catch or livelihood, although there is no known rigorous basis for this belief (Lavigne 2003).

Many of the seal deaths in Tasmania are reported by the aquaculture industry and most salmonid growers are proactive in addressing and mitigating the causes of seal deaths around farms. The nature and mitigation of these interactions has been the subject of investigation over the past 10 years (Pemberton & Shaughnessy 1993, Pemberton

*et al.* 1995, Schotte & Pemberton 2000). This study describes the number and cause of reported fur seal deaths (where known) in Tasmanian waters between 1998 and 2005 (inclusive) and compares these data to seal deaths documented elsewhere.

## MATERIALS AND METHODS

### Obtaining information about fur seal deaths

The Tasmanian Government Department of Primary Industries, Parks, Water and Environment has documented the deaths of fur seals in Tasmania since the 1980s. Since 1998, efforts were made to further investigate all reported fur seal deaths with post-mortem examinations performed to determine the cause of death, wherever possible, by experienced veterinarians or biologists. The level of information recorded for each case varied, but cause of death, species, sex and status (adult, subadult, pup) were the parameters of interest for the purposes of this study. The ability to obtain this information was dependent on the degree of decomposition of the carcass at the time of inspection. Most reports of fur seal deaths were provided by the aquaculture industry, members of the public or officers from the Tasmanian government agencies described above. Although the search effort and reporting frequency cannot be quantified between 1998 and 2005, it was considered consistent enough to allow the meaningful comparison of data between and within these years.

### Determining the cause of death

In many cases the carcasses were too decomposed to confidently ascertain a definitive cause of death. Only seals that appeared to have died in the same calendar year as they were found are reported here and the skeletal or mummified remains of seals where no approximate time of death could be ascertained are not included in the analyses. Causes of death were classified into seven categories:

Unknown – no conclusive cause of death could be identified;

Relocation – seal died as part of the aquaculture relocation operation;

Shot – seal was conclusively identified as having been shot (see below);

Likely shot – reports or injuries were consistent with a shooting death; however, the shooting was not confirmed by autopsy or scans;

Fish farm – seal died due to an interaction with a salmonid fish farm;

Other human – includes boat strikes or deliberate killing by means other than shooting; and

Natural causes – includes death from old age, malnutrition, interactions with other seals, shark attacks and disease.

Techniques have been refined in recent years to improve the assessment of cause of death. The use of X-rays and more recently Computed Tomography (CT) scans has allowed more detailed assessment of fur seal carcasses and allowed the presence of ammunition particles to be definitively identified where present (pl. 1).

### Identification, sex and age

The species of seal (either Australian Fur Seal or New Zealand Fur Seal) was identified on the basis of a suite of unique morphological and auditory characteristics (Goldsworthy *et al.* 1997). For the purposes of this manuscript, following Pemberton *et al.* (1993) and our extensive experience with fur seals of both species, Australian Fur Seals exceeding 180 kg and 2 m in length were classed as adults while New Zealand Fur Seals were classed as adults if they exceeded 140 kg and 1.4 m in length.

Post-canine teeth were collected from subadult and adult dead seals where possible. These were used to determine the age of seals by counting the layers of cementum in the teeth. The post-canine tooth was chemically decalcified, then sectioned longitudinally (0.025 mm) on a freezing

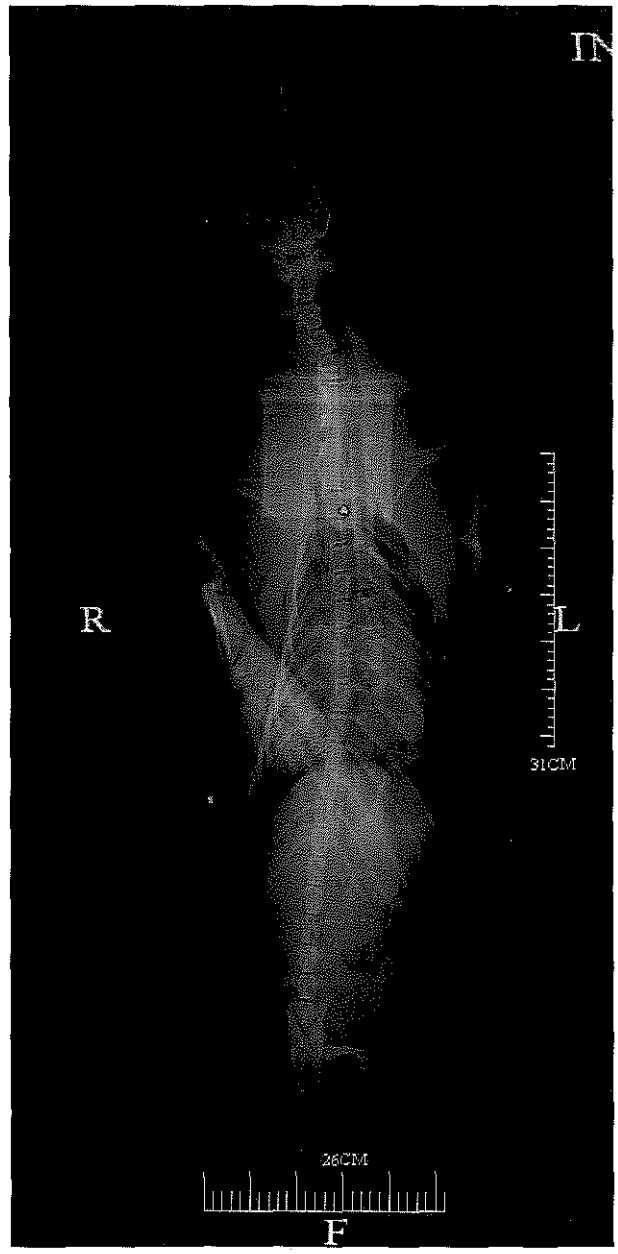


*PLATE 1*
*A CT scan of a dead New Zealand Fur Seal clearly showing two fragments of .22 caliber ammunition.*

microtome. Tooth sections were then stained with haematoxylin before being mounted on glass microscope slides. Sections were viewed under a dissecting microscope and growth layers counted to determine age. Ageing is generally accurate to within one to two years. Determination of age from teeth from older seals (>10 years) are less accurate than those from younger ones. As there is no reference collection of teeth from known age animals in these species, the precise error level is not known. This methodology is similar to that used in other studies on ageing otariid seals (e.g., Arnould & Warneke 2002, Childerhouse *et al.* 2004).

### Spatial and temporal trends in distribution

Data on dead fur seals from 1998 to 2005 inclusive were collated into a relational database (Access 2000 – Microsoft) that was used to conduct the temporal analyses. These data (including latitude and longitude) were also exported into GIS software (Manifold 6.5 Professional – Manifold Systems), which was used to carry out the spatial analyses.

## RESULTS

### Documented cases of seal mortalities

In all, 504 dead fur seals were recorded in Tasmanian waters between 1998 and 2005. Excluding dependent pups (90 individuals – all Australian Fur Seals), most of the seals were identified as Australian (80%) or New Zealand fur seals (3%) with 17% identified as fur seals but not to species level (fig. 1). The remaining 90 animals were unweaned pups, constituting 18% of all seal deaths. Most of these (80 individuals – 89%) were washed ashore on the Tasmanian mainland after drowning, probably after being washed off low-lying breeding colonies before they were able to swim adequately. The cause of death of the other pups was not identified.

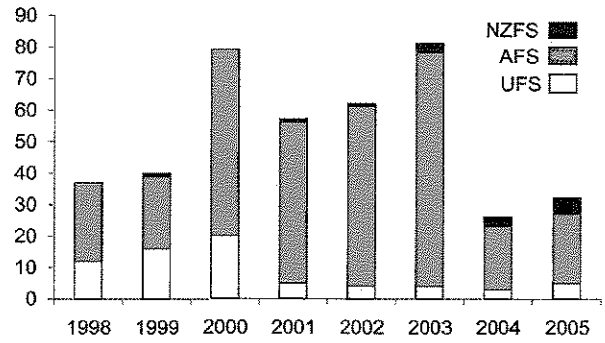


*FIG. 1 — The number of dead Australian (AFS), New Zealand (NZFS) and unidentified fur seals (UFS) recorded in Tasmania between 1998 and 2005 inclusive. Note pups are not included.*

### Cause of death of adult and subadult seals

In 205 cases the cause of death could not be ascertained conclusively (table 1). Of the remaining 209 seals, mortality due to interactions with fish farms was the most commonly reported cause of death.

Of the 112 fish farm-related deaths, 87 (78%) died as a result of being entangled in pen netting, with a further 21 (19 %) found floating on the leases, and identified as drowned after being entangled in salmonid pen netting. The remaining four seal deaths (3%) were linked to the use of "non-lethal" deterrents. In one of the latter cases a seal died from a cracker exploding after it had been ingested while the another died from injuries consistent with an explosive force close to the individual. The sex of 80% of the seals that died as a result of interactions with fish farms was determined and only one was female. Most of the males (49 individuals – 55%) were subadults with adults comprising 38% (34 individuals). The age class of the remaining 7% (six individuals) could not be determined.

**TABLE 1**

**Documented causes of mortality of Australian and New Zealand fur seals in Tasmanian waters 1998–2005**

| Year | Unknown | Relocation | Shot | Likely Shot | Fish Farm | Other Human | Natural Causes | Pups | Totals |
|---|---|---|---|---|---|---|---|---|---|
| 1998 | 6 | – | 3 | – | 2 | 1 | 25 | 1 | 37 |
| 1999 | 32 | – | 1 | – | 4 | – | 3 | 1 | 40 |
| 2000 | 39 | 2 | 3 | 6 | 27 | 2 | – | 0 | 79 |
| 2001 | 24 | 5 | 4 | 1 | 22 | 1 | – | 0 | 57 |
| 2002 | 42 | 1 | 2 | | 15 | 2 | – | 76 | 62 |
| 2003 | 35 | 4 | 3 | 8 | 23 | 1 | 7 | 12 | 81 |
| 2004 | 15 | – | 5 | 1 | 5 | – | – | 0 | 26 |
| 2005 | 12 | – | 4 | – | 14 | – | 2 | 0 | 32 |
| Totals | 205 | 12 | 25 | 16 | 112[1] | 7 | 37 | 90 | 302 |

[1] Includes four seals that died from injuries associated with the use of supposed non-lethal deterrants.

Between 1998 and 2005, 25 seals were identified as being shot in Tasmanian waters, accounting for 6% of all reported and investigated seal deaths since 1998 (table 1). A further 4% of seals died of injuries consistent with firearms wounds (likely shot); however, these were not conclusively verified by post-mortem examination or imaging techniques. Between 2000 and 2003, 12 seals died after being trapped (under permit) at farms, either in the holding cage or en route to the release site (away from the farm) in the trailer. All but one of these seals died after aspirating their own regurgitate.

Nine percent of dead seals that were investigated died from natural causes. Other human mediated deaths accounted for the final 1% of dead seals and included boat strikes (four individuals), killing through means other than shooting (two individuals – one drowned and one with broken jaw) and a final individual that died while government staff were attempting to relocate it from a public place. Overall, 172 reported and investigated seal deaths were attributed to human activities between 1998 and 2005.

## Age and sex

Of the adult and subadult fur seals, males were most commonly seen (58%), with only 6% identified as females; the sex of 36% could not be determined. Of the males, 106 (26%) were adults and 98 (24%) were subadults or juveniles. The sex of approximately 50% of pups found was not identified and there were similar numbers of males and females for those pups whose sex was identified (22 and 19 individuals respectively).

Age was determined for 68 dead male fur seals and the mean age for each cause of death is summarised in table 2. The youngest seals (excluding pups) died in the relocation process (n=4, mean age 5.5 ± 1.4 yrs) and the oldest seals died of natural causes (n=3, mean age 10.0 ± 1.7 yrs). The mean age of seals where the cause of death was not known was relatively high (n=26, mean =9.5 ± 0.9 yrs), but also had the highest range of ages (1–21 years). There were no significant differences between the mean age of individuals in the five different causes of death categories (Kruskal-Wallis, df=4, $\chi^2$ = 7.6, p=0.11).

**TABLE 2**
**Summary of cause of death and associated age in Australian Fur Seal and New Zealand Fur Seal deaths in Tasmanian waters between 1998 and 2005 inclusive**

| Cause of death | N | Mean age | Standard error |
|---|---|---|---|
| Relocation | 4 | 5.5 | 0.7 |
| Fish farm | 27 | 6.4 | 0.7 |
| Shot | 8 | 8.4 | 1.9 |
| Natural causes | 3 | 10.0 | 1.0 |
| Unknown | 26 | 9.5 | 0.9 |

## Spatial and temporal patterns

The number of documented seal deaths (excluding pups) ranged between 26 and 81 each year and were highest in 2000 and 2003 (table 1, fig. 1). Australian Fur Seal deaths were at their lowest levels in 2004 and 2005 while the number of dead New Zealand Fur Seals increased from 2002 to 2005. Seal pup deaths were episodic in occurrence; most (80%) occurred in a single event in December 2002 (table 1). There was also some annual variation in relation to the cause of death; deaths reported by fish farm personnel were highest in 2000 and lowest in 1998 (table 1).

The spatial and seasonal patterns of reported seal deaths varied with the cause of death. Most individual deaths occurred in the southeast quadrant of Tasmania and all reported mortality events associated with fish farms and most of the shooting deaths were reported in this region (fig. 2, table 3). The lowest number of seal deaths was reported in the southwest and northwest quadrants. All dead pups were found on the north and northeast coasts.

There was no discernible pattern in the timing of aggregated fur seal deaths throughout the year. However, there were seasonal differences in cause of death (table 4). Mortality events with an unknown cause of death were higher in the months of January and February, and most seal deaths that occurred during the relocation process between 2000 and 2003 also occurred during the summer months (table 4). Seal shootings peaked in January; however, there was little evidence of any overall trend (table 4). Seal deaths

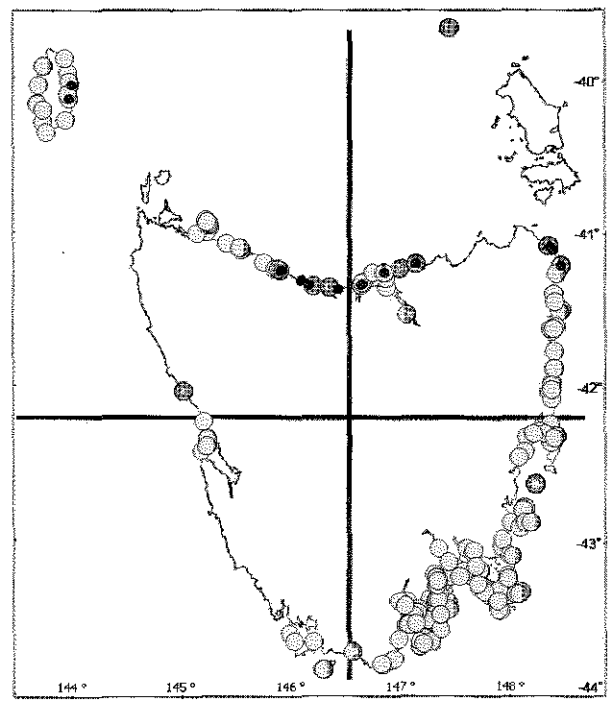


*FIG. 2. — Location of fur seal mortality events around Tasmania, 1998–2005. Juveniles, subadults and adults are shown as large grey points; pup mortality events are shown as small black points.*

**TABLE 3**
**Cause of death of adults and subadult fur seals by Tasmanian region 1998–2005 inclusive[1]**

| Region[2] | Unknown | Relocation | Shot | Fish Farm | Other Human | Natural Causes | Adults | Pups |
|---|---|---|---|---|---|---|---|---|
| NE | 44 | 1 | 1 | 0 | 0 | 7 | 53 | 81 |
| NW | 26 | 0 | 11 | 0 | 0 | 20 | 57 | 9 |
| SE | 114 | 11 | 29 | 112 | 6 | 11 | 283 | |
| SW | 19 | 0 | 1 | 0 | 1 | 0 | 21 | |

[1] Table 2 totals differ from Table 1 as one unknown death had no reliable location data.
[2] See Figure 2.

associated with fish farms were higher between May and September, and dropped to much lower levels during the summer months (table 4). There was no discernible trend in the other deaths associated with humans while deaths attributed to natural causes were highest in December (table 4).

## DISCUSSION

### Overview

This is the first study of this kind in Tasmania. Its success has been made possible through the cooperation of a number of government agencies and the salmon aquaculture industry.

The high proportion of Australian Fur Seals found dead in Tasmanian waters reflects the abundance of this species relative to the New Zealand Fur Seal. Male fur seals were found dead much more commonly than females. This is likely attributable to their propensity to disperse more widely from the breeding colonies, particularly into southeast Tasmanian waters (Kirkwood *et al.* 2002) where the human population is greatest (SOE 2009) and where most fish farms are located (Schotte & Pemberton 2002).

Seal interactions with wild fisheries and aquaculture are not unique to Tasmania. Similar problems occur in other parts of Australia and in other countries (Wickens *et al.* 1992, Mawson & Coughran 1999, Norman 2000, Lalas & Bradshaw 2001, David & Wickens 2003, Shaughnessy *et al.* 2003, Kemper *et al.* 2003). Salmonid aquaculture is a significant industry in Tasmania, producing in the vicinity of 20 000 tonnes of Atlantic Salmon (*Salmo salar* Linnaeus, 1758) each year worth about AUD$160 million. Ninety percent of salmonid fish farming occurs in the southeast of the state, in the same region as many of the non-breeding seal haulout sites.

### Cause of death of adult and subadult seals

Over 40% of reported and investigated fur seal deaths could be directly attributable to anthropogenic influences. Many of the cases where the cause of death was not known involved healthy subadult or adult seals and it is possible that their deaths were human-mediated events.

Deaths during the relocation process peaked in the summer months and this is probably attributable to the increased chance of heat stress and dehydration due to the higher temperatures experienced around this time of

**TABLE 4**
**Timing of mortality events in relation to the cause of death in Australian Fur Seal and New Zealand Fur Seals in Tasmanian waters from pooled data (1998–2005)**

| Month | All | Unknown | Relocation | Shot/likely shot | Fish Farm | Other Human | Natural Causes |
|---|---|---|---|---|---|---|---|
| Jan | 45 | 30 | 2 | 8 | 2 | 1 | 2 |
| Feb | 34 | 22 | 4 | 3 | 3 | 2 | 0 |
| March | 26 | 16 | 3 | 1 | 4 | 1 | 1 |
| April | 22 | 11 | 0 | 4 | 7 | 0 | 0 |
| May | 28 | 9 | 1 | 2 | 16 | 0 | 0 |
| June | 34 | 11 | 0 | 2 | 17 | 1 | 3 |
| July | 39 | 10 | 0 | 4 | 23 | 1 | 1 |
| Aug | 33 | 18 | 0 | 2 | 13 | 0 | 0 |
| Sep | 40 | 18 | 1 | 4 | 16 | 0 | 1 |
| Oct | 21 | 13 | 0 | 3 | 4 | 0 | 1 |
| Nov | 29 | 17 | 0 | 3 | 6 | 1 | 2 |
| Dec | 26 | 20 | 1 | 0 | 1 | 0 | 4 |

the year. Although 12 seals died during the relocation program between 2000 and 2003 there were no deaths associated with this program in 2004 or 2005. In response to the deaths that occurred prior to 2003, the Tasmanian State Government undertook an extensive revision of protocols for holding and moving seals and this has been instrumental in reducing the number of seal deaths to zero. Critical to these was the use of archival temperature recorders in relocation trailers to ascertain safe transport ambient temperatures.

Seal deaths associated with fish farm marine activities were lowest in summer when fewer seals attended the farm as they likely to be attending breeding colonies (Robinson *et al.* 2008b). Satellite tracking has shown that male fur seals tend to forage over shelf waters in preference to the shallower waters around fish farms at this time of year (Robinson *et al.* 2008a). Most of the deaths were caused by entanglement in fish farm netting. The most common type of entanglement involved seals getting caught in the predator nets, a barrier set of nets specifically designed to stop seals accessing the pen and the fish inside. Seals may try and broach these predator nets to get access to fish and when they are partially or fully successful they often become trapped underwater and drown. Net entanglements are a product of nets not retaining their inherent structure. This is the result of the difficulty of tensioning a construction that is both round in two dimensions and flat in the third (Schotte & Pemberton 2002). The growth and expansion of the salmonid fish farm industry in Tasmania will likely result in increasing interactions with seals.

The number of seals reported as shot and killed in Tasmanian waters has remained consistent since 1998. The legal shooting of seals under permit has been tried as a method of reducing the negative impacts in several fisheries (Kemper *et al.* 2003) but is unlikely to be a useful solution in the long term (Lavigne 2003). Educating fishers and other users of marine resources is one way of reducing the number of seals killed in this manner; however, ingrained attitudes are sometimes difficult to change in the short term. More recently, application of carcass imaging techniques has allowed seals to be conclusively identified as shot (see pl. 1). Recent media attention associated with seal shootings has increased the public awareness of this issue and may prove to be one of the more effective tools in educating both the general public and industry.

### Mitigating the deaths of fur seals

Trapping and relocation of seals from salmonid fish farms began in 1990 in an effort to reduce the impact of seals at farms (Hume *et al.* 2002). This practice may offer some short-term relief to farms but its efficacy in reducing seal interactions in the long term is questionable (Kemper *et al.* 2003, Robinson *et al.* 2008b). Further efforts to address and mitigate the impacts of seals on the aquaculture industry resulted in the development of a Management Strategy in 2002 by the Tasmanian Government, in conjunction with the fishing industry (DPIWE 2002). This Management Strategy suggested the implementation of a number of practices including: no feeding of seals, utilising better designed nets and adequate staff training. The implementation of these measures has reduced the economic impact of the seals on farms, and probably has resulted in the decrease observed in the number of seal deaths at fish farms since 2003. Longer-term reductions in seal mortality are only likely to be achieved through further changes in the set-up and/or design of pens and associated predator nets.

### Comparison of seal deaths with other locations

Published data on dead seals from other locations are rare. However, in a report on dead and injured seals in Western Australia, 179 dead pinnipeds were recorded between 1980 and 1996 with 51 deaths attributed to human activities (Mawson & Coughran 1999). Differences in the species and size of breeding colonies in adjacent waters and unknown reporting biases confound direct comparisons between Tasmania and Western Australia. However, both the overall number of seal deaths and number of seal deaths attributed to anthropogenic influences over an eight-year period in Tasmania are considerably higher than those reported in Western Australia.

A report into stranded marine mammals in New Zealand between 1999 and 2002 reported 44 New Zealand Fur Seals, one New Zealand Sea Lion, *Phocarctos hookeri* Gray, 1884, and one Subantarctic Fur Seal, *Arctocephalus tropicalis* Gray, 1872, over a three-year period (Duignan 2003). While these are much lower numbers than those found in Tasmanian waters, direct comparisons are again confounded by differences in reporting and investigation effort. No details on the causes of death were provided in the New Zealand report.

## CONCLUSION

It is impossible to precisely quantify the number of dead seals that occur on the Tasmanian coast as many would be undetected and others not reported, particularly in the southwest and northwest regions where coastal access and population numbers are considerably lower than elsewhere. However, this study does show the impact of anthropogenic forces on fur seals in Tasmania and highlights the value of monitoring the number of dead seals and ascertaining the cause of death. In order to further reduce fur seal mortality in Tasmanian waters, efforts should focus on working with fish farmers to increase the efficacy and safety of the net and pen configurations. Ongoing education, of both the general public, recreational fishing groups and industry, regarding seals and their legitimate place in the marine ecosystem, may also prove to be an effective tool in mitigating the occasionally negative perception of seals and their role in the marine environment.

## ACKNOWLEDGEMENTS

We thank the Princess Melikoff Marine Mammal Conservation Trust and Tasmanian Perpetual Trustees for funding much of this work. The Department of Primary Industries, Parks, Water and Environment also provided considerable logistic and resource support. Thanks to Mike Greenwood, Jody Sargison, Sue Robinson, Matt Webb and the Seal Relocation Team for assistance with processing and transporting dead seals. Thanks also to the Tasmanian Parks and Wildlife Service for reporting dead seals around Tasmania and assisting with their processing and transport. We gratefully acknowledge John Gibbens who undertook the ageing of the teeth. Dr Barrie Wells and other veterinary and medical staff have also

provided invaluable training and assistance in the necropsies. This manuscript was much improved by the comments of four anonymous referees.

## REFERENCES

**Arnould, J.P.Y. & Littnan, C.L.** 2000: Pup production and breeding areas of Australian Fur Seals *Arctocephalus pusillus doriferus* at Kanowna Island and the Skerries in northeastern Bass Strait. *Australian Mammalogy* **22**: 51–55.

**Arnould, J.P. & Warneke, R.M.** 2002: Growth and condition in Australian Fur Seals (*Arctocephalus pusillus doriferus*) (Carnivora:Pinnepedia). *Australian Journal of Zoology* **50**: 53–66.

**Arnould, J.P.Y., Boyd, I.L. & Warneke, R.M.** 2003: Historical dynamics of the Australian Fur Seal population: Evidence of regulation by man. *Canadian Journal of Zoology* **81**: 1428–1436.

**Childerhouse, S., Dickie, G. & Hessel, G.** 2004: Ageing live New Zealand Sea Lions (*Phocarctos hookeri*) using the first post-canine tooth. *Wildlife Research* **31**: 177–181.

**David, J. & Wickens, P.** 2003: Management of Cape Fur Seals and fisheries in South Africa. *In* Gales, N.J., Hindell, M. & Kirkwood, R. (eds): *Marine Mammals: Fisheries, tourism and management issues*. CSIRO Publishing, Colllingwood: 116–135.

**DPIWE** 2002: A Seal/Fishery Interaction Management Strategy. Department of Primary Industries, Water and Environment, Tasmania: 11 pp.

**Duignan, P.J.** 2003: Disease investigations in stranded marine mammals, 1999–2002. DOC Internal series 104. Department of Conservation, New Zealand.

**Goldsworthy, S.D., Pemberton, D. & Warneke, R.M.** 1997: The field identification of Australian and New Zealand Fur Seals (*Arctocephalus* spp.) based on external characteristics. *In* Hindell, M. & Kemper, C. (eds): *Marine Mammal Research in the Southern Hemisphere. Volume 1. Status, Ecology and Medicine.* Surrey Beatty and Sons, Chipping Norton, NSW: 63–71.

**Hume, F., Pemberton, D., Gales, R., Brothers, N. & Greenwood, M.** 2002: An assessment of the trapping and relocation of seals from salmonid fish farms in Tasmania, 1999-2000. *Papers and Proceedings of the Royal Society of Tasmania* **136**: 1–6.

**Kemper, C., Pemberton, D., Cawthorn, M., Heinreich, S., Mann, J., Wursig, B., Shaughnessy, P. & Gales, R.** 2003: Aquaculture and marine mammals: Coexistence or conflict. *In* Gales, N.J., Hindell, M. & Kirkwood, R. (eds): *Marine Mammals: fisheries, tourism and management issues.* CSIRO Publishing, Collingwood: 208–228.

**Kirkwood, R., Gales, N., Lynch, M. & Dann, P.** 2002. Satellite tracker deployments on adult, male Australian Fur Seals *Arctocephalus pusillus doriferus*: methods and preliminary results. *Australian Mammalogy* **24**: 73–83.

**Kirkwood, R., Gales, R., Terauds, A., Arnould, J.P.Y., Pemberton, D., Shaughnessy, P.D., Mitchell, A.T. & Gibbens, J.** 2005: Pup production and population trends of the Australian Fur Seal (*Arctocephalus pusillus doriferus*). *Marine Mammal Science* **21**: 260–282.

**Lalas, C. & Bradshaw, C.J.A.** 2001: Folklore and chimerical numbers: review of a millennium of interaction between Fur Seals and humans in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research* **35**: 477–497.

**Lavigne, D.M.** 2003 Marine mammals and fisheries: the role of science in the culling debate. *In* Gales, N.J., Hindell, M. & Kirkwood, R. (eds): *Marine Mammals: fisheries, tourism and management issues.* CSIRO Publishing, Collingwood: 31–47.

**Ling, J.K.** 1999: Exploitation of Fur Seals and sea lions from Australia, New Zealand and adjacent Sub-antarctic islands during the 18th, 19th and 20th centuries. *Australian Zoologist* **31**: 323–350.

**Mawson, P.R. & Coughran, D.K. 1999:** Records of sick, injured and dead pinnipeds in Western Australia 1980-1996. *Proceedings of the Royal Society of Western Australia* **82**: 121–128.

**Norman, F.I.** 2000: Preliminary investigation of the bycatch of marine birds and mammals in inshore commercial fisheries, Victoria, Australia. *Biological Conservation* **92**: 217–226.

**Page, B., McKenzie, J., Sumner, M.D., Coyne, M.D. & Goldsworthy, S.D.** 2006: Spatial separation of foraging habitats among New Zealand Fur Seals, *Marine Ecology Progress Series* **323**: 263–279.

**Pemberton, D. & Shaughnessy, P.D.** 1993: Interaction between seals and marine fish farms in Tasmania, and management of the problem. *Aquatic Conservation - Marine and Freshwater Ecosystems* **3**: 149–158.

**Pemberton, D., Kirkwood, R., Gales, R. & Renouf, D.** 1993: Size and shape of male Australian fur seals, *Arctocephalus pusillus doriferus*. *Marine Mammal Science* **9**: 99–103.

**Pemberton, D., Gales, R. & Skira, I.** 1995: Interactions between Seals and Fisheries: A Clash of Vertebrate Predators. *In* Proceedings of 10th Australian Vertebrate Pest Control Conference. Hobart, Tasmania: 249–254

**Pemberton, D. & Kirkwood, R.J.** 1994: Pup production and distribution of the Australian Fur-Seal, *Arctocephalus pusillus doriferus*, in Tasmania. *Wildlife Research* **21**: 341–352.

**Pemberton, D. & Gales, R.** 2004: Australian Fur Seals (*Arctocephalus pusillus doriferus*) breeding in Tasmania: population size and status. *Wildlife Research* **31**: 301–309.

**Robinson, S., Gales, R., Terauds, A. & Greenwood, M.** 2008a: Movements of Fur Seals following relocation from fish farms. *Aquatic Conservation* **18**: 1189–1199.

**Robinson, S., Terauds, A., Gales, R. & Greenwood, M.** 2008b: Mitigating fur seal interactions: relocation from Tasmanian aquaculture farms. *Aquatic Conservation* **18**: 1180–1188.

**Schotte, R. & Pemberton, D.** 2002: Anti-predator stock protection research project – Final report, FRDC 99/361: 84pp.

**Shaughnessy, P.D., Troy, S.K., Kirkwood, R.J. & Nicholls, A.O.** 2000: Australian Fur Seals at Seal Rocks, Victoria: pup abundance by mark-recapture estimation shows continued increase. *Wildlife Research* **27**: 629–633.

**Shaughnessy, P.D., Kirkwood, R.J. & Warneke, R.M.** 2002: Australian Fur Seals, *Arctocephalus pusillus doriferus*: pup numbers at Lady Julia Percy Island, Victoria, and a synthesis of the species' population status. *Wildlife Research* **29**: 185–192.

**Shaughnessy, P., Kirkwood, R., Cawthorn, M., Kemper, C. & Pemberton, D.** 2003: Pinnipeds, cetaceans and fisheries in Australia: A review of operational interactions. *In* Gales, N.J., Hindell, M. & Kirkwood, R. (eds): *Marine Mammals: fisheries, tourism and management issues.* CSIRO Publishing, Collingwood: 208–228.

**S.O.E. (State of the Environment) Tasmania** 2009: Tasmanian Planning Commission, last modified March 2010, Tasmanian Planning Commission, Hobart. <http:/soer.justice.tas.gov.au/2009/index.php>

**Wickens, P.A., Japp, D.W., Shelton, P.A., Kriel, F., Goosen, P.C., Rose, B., Augustyn, C.J., Bross, C.A., Penney, A.J. & Krohn, R.G.** 1992: Seals and Fisheries in South Africa – Competition and conflict. *South African Journal of Marine Science* **12**: 773–789.

(accepted 6 April 2010)