Exxon Valdez Oil Spill
Restoration Project Final Report

Synthesis of Nearshore Recovery following the 1989 *Exxon Valdez* Oil Spill: Trends in Sea Otter Population Abundance in Western Prince William Sound

Restoration Projects 070808, 070808A, and 090808
Final Report

J.L. Bodkin, B.E. Ballachey, and G.G. Esslinger

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Synthesis of Nearshore Recovery following the 1989 *Exxon Valdez* Oil Spill:
Trends in Sea Otter Population Abundance in Western Prince William Sound

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STUDY HISTORY: Sea otter populations in western Prince William Sound (WPWS) were injured as a result of the 1989 *Exxon Valdez* oil spill (EVOS) (Ballachey et al. 1994). The U. S. Geological Survey, Alaska Science Center conducted aerial surveys of sea otters in Prince William Sound from 1993-2009. Analysis of surveys conducted through 2000 describes significant increases in abundance in much of the spill area (Bodkin et al. 2002), but that in areas most severely influenced by the spill, no increases were evident and abundance remained at about half the pre-spill level (Dean et al. 2000). Subsequent to 2000, aerial surveys were conducted under EVOS Projects –0423 and –0620 and most recently under –0808 and are reported herein. Due to the complexity and scope of work engaged, and the ongoing status of some of that work, independent chapters representing the major areas of research will be submitted independently, as work is completed. This report represents one chapter in the final report for EVOS Project –0808, specific to estimates and trends of sea otter abundance over time.

ABSTRACT: Sea otters in western Prince William Sound (WPWS) and elsewhere in the Gulf of Alaska suffered wide-spread mortality as a result of oiling following the 1989 T/V *Exxon Valdez* oil spill. Following the spill, extensive efforts by both public and private scientists have been directed toward identifying and understanding long term consequences of the spill and the process of recovery. We conducted annual aerial surveys of sea otter abundance from 1993-2009 (except for 2001 and 2006) in WPWS. We observed an increasing trend in population abundance at the scale of WPWS through 2000 at an average annual rate of 4%. However, at northern Knight Island where oiling was heaviest and sea otter mortality highest, no increase in abundance was evident by 2000. We continued to see significant increase in abundance at the scale of WPWS between 2001and 2009, with an average annual rate of increase from 1993-2009 of 2.6%. We estimated the 2009 population size of WPWS to be 3,959 (se = 653), nearly 2,000 more than the first post-spill estimate in 1993. Surveys since 2003 have also identified a significant increasing trend at the heavily oiled site in northern Knight Island, averaging about +25% annually and resulting in a 2009 estimated population size of 116 (se=19). Although the 2009 estimate for northern Knight Island remains about 30% less than the pre-spill estimate of 165, we interpret this trend as strong evidence of a trajectory toward recovery of spill-affected sea otter populations in WPWS.

KEY WORDS: population estimates, sea otters, trends, Prince William Sound.

PROJECT DATA:

Description of data – Data on the distribution and abundance of sea otters were collected in Prince William Sound, Alaska. Data were entered into a computer and are archived with the U.S. Geological Survey, Alaska Science Center, which resides in Anchorage, Alaska.

Format – All data are available as Microsoft Excel files, Arc GIS files, or comma delimited ASCII files.

Custodian – James L. Bodkin, Research Wildlife Biologist and Project Leader, Marine and Freshwater Ecology Branch, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska 99508.

Internet – Project data are available at the website for the *Exxon Valdez* Oil Spill Trustee Council, under the Project Search section for project 090808: http://www.evostc.state.ak.us/projects/

CITATION: Bodkin, J.L., B.E. Ballachey, and G.G. Esslinger. 2011. Synthesis of nearshore recovery following the 1989 *Exxon Valdez* oil spill: Trends in sea otter population abundance in Western Prince William Sound. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Projects 070808, 070808A, and 090808), U. S. Geological Survey, Alaska Science Center, Anchorage, Alaska.

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Abstract

Sea otters in western Prince William Sound (WPWS) and elsewhere in the Gulf of Alaska suffered wide-spread mortality as a result of oiling following the 1989 T/V *Exxon Valdez* oil spill. Following the spill, extensive efforts by both public and private scientists have been directed toward identifying and understanding long term consequences of the spill and the process of recovery. We conducted annual aerial surveys of sea otter abundance from 1993-2009 (except for 2001 and 2006) in WPWS. We observed an increasing trend in population abundance at the scale of WPWS through 2000 at an average annual rate of 4%. However, at northern Knight Island where oiling was heaviest and sea otter mortality highest, no increase in abundance was evident by 2000. We continued to see significant increase in abundance at the scale of WPWS between 2001and 2009, with an average annual rate of increase from 1993-2009 of 2.6%. We estimated the 2009 population size of WPWS to be 3,959 (se = 653), nearly 2,000 more than the first post-spill estimate in 1993. Surveys since 2003 have also identified a significant increasing trend at the heavily oiled site in northern Knight Island, averaging about +25% annually and resulting in a 2009 estimated population size of 116 (se=19). Although the 2009 estimate for northern Knight Island remains about 30% less than the prespill estimate of 165, we interpret this trend as strong evidence of a trajectory toward recovery of spill-affected sea otter populations in WPWS

Introduction

Sea otter populations in western Prince William Sound (WPWS) were injured as a result of the 1989 *Exxon Valdez* oil spill (EVOS) (Ballachey et al. 1994). Effects included both acute mortality, resulting from contact with spilled oil in the days and months following the spill, and chronic effects, resulting from sub-lethal initial exposure or protracted exposure to lingering oil, or indirect effects, e.g., reduced prey populations or other ecosystem disturbances (Peterson 2000, Peterson et al. 2003). Estimates of sea otter mortality due to acute effects of the oil spill in WPWS only ranged from 750 to 2,650 individuals (Garrott et al. 1993, Garshelis 1997). The disparity among acute mortality estimates largely reflects the lack of accurate pre-spill estimates of sea otter population size. Using population models, Udevitz et al. (1996) predicted recovery of the WPWS sea otter population in 10 to 23 years, with maximum annual growth rates from 0.10-0.14.

Since 1993 we have conducted aerial surveys of sea otter populations in WPWS annually to track the progress of sea otter recovery, except in 2001 and 2006. Results of sea otter population surveys through 2000 demonstrated a significant increase of nearly 600 animals in WPWS, resulting in a statistically significant average annual increase of 4% per year since 1993 (Bodkin et al. 2002). This increase at the scale of WPWS was considered indicative of progress toward recovery, although the average annual rate of increase was about half the long-term growth rate experienced in PWS earlier in the 20th century (Bodkin et al. 2002). Additionally, Dean et al. (2000) and Bodkin et al. (2002) describe a situation at northern Knight Island in WPWS where there was no evidence of increase in sea otter abundance by 2000, more than a decade after the spill, and abundance was less than half of the population size prior to the spill.

Recovery of the PWS ecosystem from the *Exxon Valdez* oil spill may not be considered complete until individual animals are no longer exposed to lingering oil from the spill, and when populations reach pre-spill levels of abundance (Exxon Valdez Oil Spill Restoration Plan, EVOS Trustee Council 2006). The results of aerial surveys of sea otters in WPWS provide a means to evaluate progress toward recovery goals. Our objective in this report is to report the results of aerial surveys to estimate sea otter abundance in WPWS, and at previously oiled Knight Island and unoiled Montague Island conducted through 2009. Here, we present those abundance estimates derived from the aerial surveys and evaluate the trends in abundance evident in the time series of data from 1993-2009.

Study area

Our survey efforts were focused on WPWS, the site of previous EVOS sea otter studies (Burn 1994, Bodkin et al. 2002, Dean et al. 2000, Dean et al. 2002, Ballachey et al. 2003). We surveyed sea otter population sizes at two geographical scales: 1) a regional scale defined as WPWS, and 2) an intensive scale within WPWS which included one oiled site and one unoiled site. The WPWS study area included all oiled areas of Prince William Sound as well as areas contiguous to oiled areas (Figure 1). The intensive survey areas included an oiled area identified as the shorelines of the northern Knight Island archipelago (Figure 2). Oiling in 1989 was heaviest here, and population levels of sea otters are generally lower here than in other areas of PWS that were not oiled (Bodkin and Udevitz 1999, Dean et al. 2002). The northern Knight Island survey area consisted of 168.1 km^2, including 93.9 $km^2$of low density and 74.2 km^2 of high density stratum. The intensive survey area also included an unoiled area along the northwestern shore of Montague Island between (Figure 2). The Montague Island survey area consisted of 90 km^2, including 20.6 $km^2$of low density and 20.6 km^2 of high density stratum.

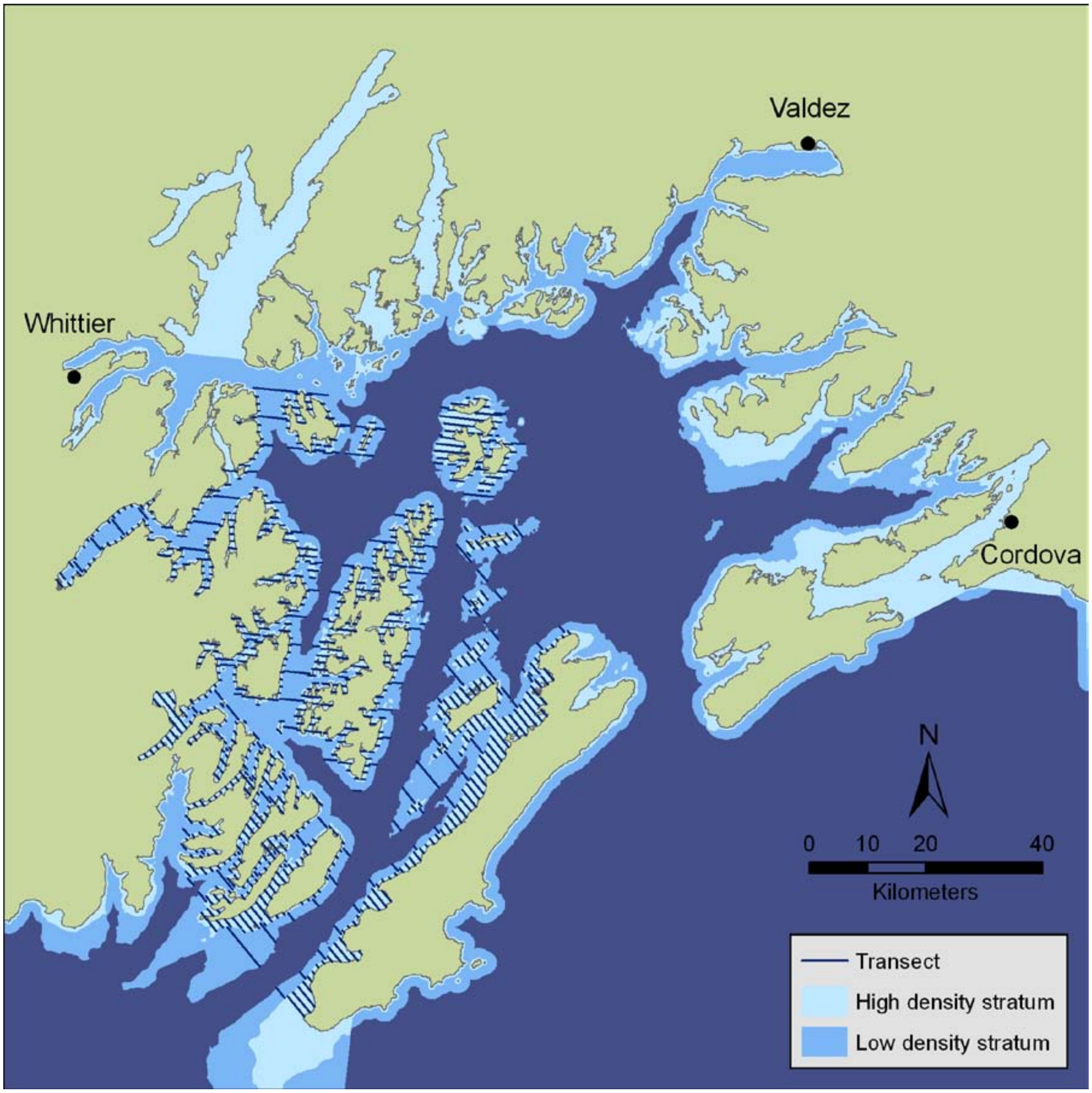

Figure 1. Prince William Sound, Alaska. Blue lines delineate the Western Prince William Sound (WPWS) transects surveyed and collectively represent the survey area. High density stratum are generally defined by water depths < 40 m and are sampled at a higher intensity than in the low stratum that extends from the 40 m to the 200 m depth contour.

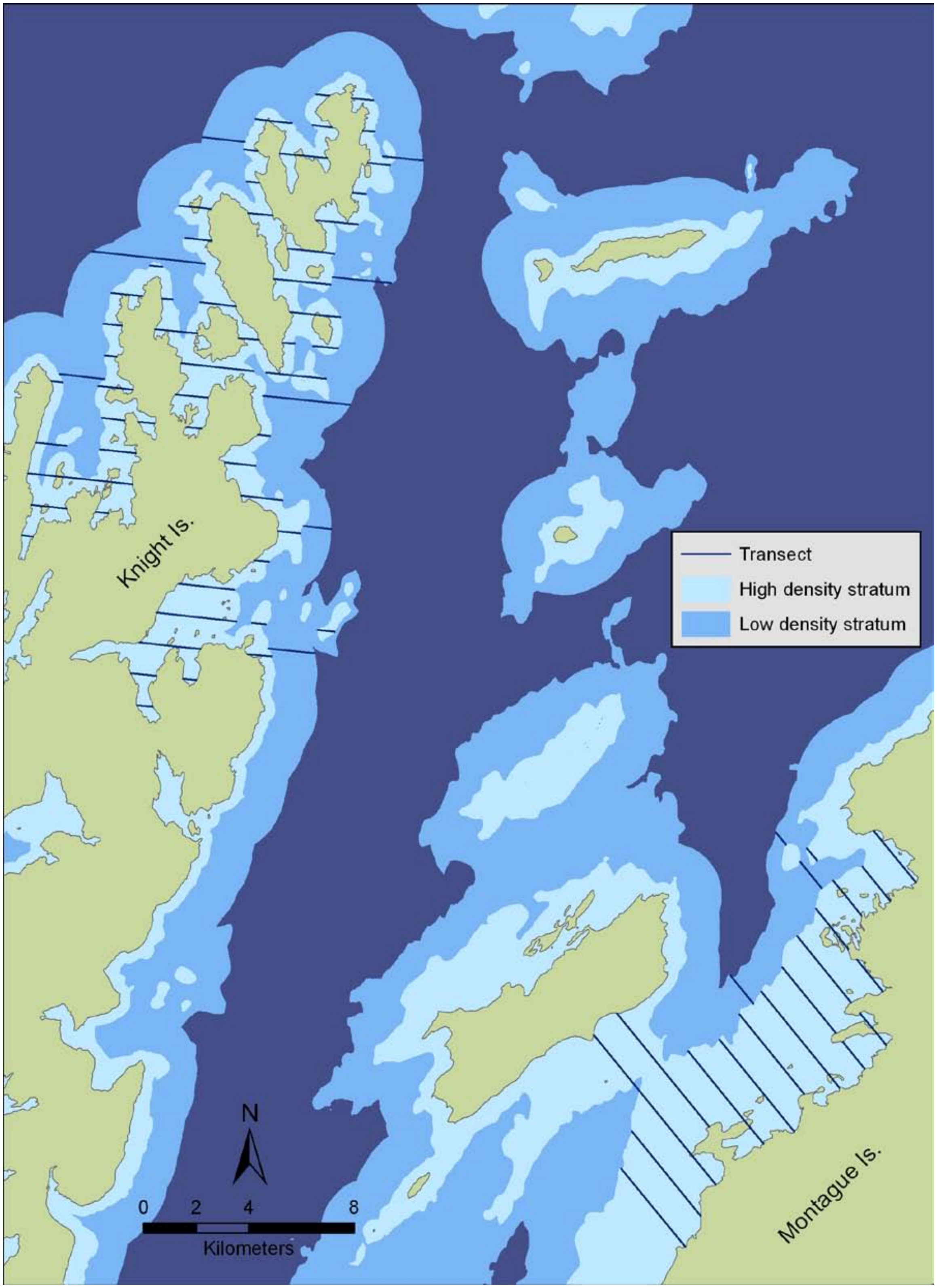

Figure 2. Northern Knight Island (oiled) and Montague Island (unoiled) intensive study areas in western Prince William Sound. Blue lines delineate transects surveyed and collectively represent the survey area. High density stratum are generally defined by

water depths < 40 m and are sampled at a higher intensity than in the low stratum that extends from the 40 m to the 200 m depth contour.

Methods

The aerial surveys of sea otters consist of two components: (1) strip transect counts and (2) intensive search units, which are fully described in Bodkin and Udevitz (1999). Sea otter habitat was sampled in two strata, high density and low density, distinguished by distance from shore and depth contour. Survey effort was allocated proportionally to expected sea otter abundance by adjusting the systematic spacing of transects within each strata, with approximately 80% of the effort allocated to the high density stratum. Transects with a 400 meter strip width on one side of a fixed-wing aircraft were surveyed by a single observer at an air speed of 104 kph (29 m/sec) and altitude of 91 m. The observer searched forward as far as conditions allowed and out laterally 400 m, indicated by marks on the aircraft struts, and recorded each otter group size and location on a transect map. A group was defined as one or more otters spaced less than three otter lengths apart. Intensive search units (ISU's) were used to estimate the proportion of sea otters not detected on strip transect counts, and result in correction factors which are used to adjust strip counts for animals not detected. ISU's were conducted at intervals to provide a sample distribution throughout the survey period, and were initiated by the sighting of a group. ISU’s consisted of five concentric circles flown within the 400 m strip perpendicular to the group on the transect that initiated the ISU. Groups of sea otters initiating each ISU are not included in calculating detection. Pups are included in the population estimate as independent sea otters.

To increase precision in estimates for the intensive oiled (northern Knight Island) and unoiled (Montague Island) areas, up to five replicate surveys were conducted using the same techniques described in Bodkin and Udevitz (1999). Replicate surveys were conducted during the same time period as the WPWS surveys (mid-summer; June-July). Rates of change in population estimates over time were calculated by regressing the log (*N*) of estimates over years. A single observer (JLB) conducted all surveys.

Results

<u>Western Prince William Sound</u>: In 1993 we estimated a WPWS sea otter population size of 2,054 (se=698) and in 2009 we estimated a population size of 3,958 (se = 653) sea otters in WPWS. With the exception of 2001 and 2006, we estimated sea otter abundance in WPWS since 1993 (Figure 3, Table 1). From 1993 through 2000, a significant positive average annual growth rate of about 4% ($r^2 = 0.56$, $p = 0.03$) was evident. In 2002 it appeared as though there was an overall decline in WPWS sea otter abundance, but subsequent estimates confirm the significant long-term trend toward an increasing sea otter population in WPWS. The average annual increase over the 17 year period (1993-2009) is about 2.6% ($r^2 = 0.43$, $p = 0.02$). The 2009 sea otter population estimate for WPWS (3,958) represents an increase of 1,900 animals since we initiated

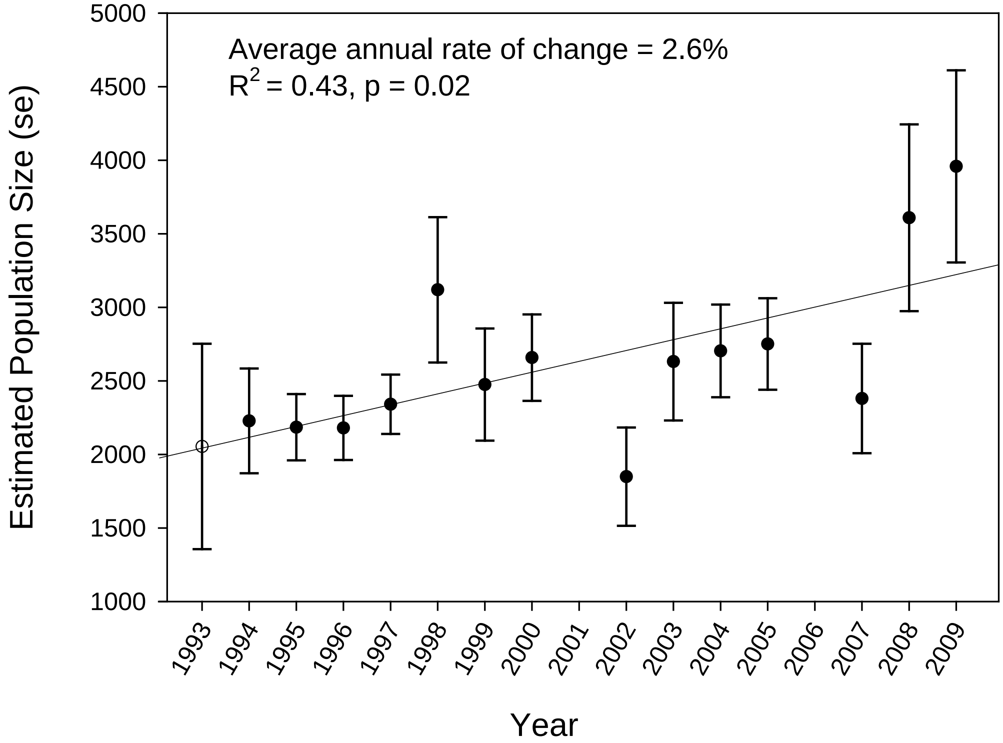

Figure 3. Sea otter population trend in western Prince William Sound, 1993-2009. Line is linear regression fitted to all points, bars indicate ±1 SE.

aerial surveys in 1993 (2,054) following the EVOS (Table 1). Distributions and relative abundance of sea otters detected during the WPWS surveys in 2008 and 2009 are provided in Figures 4 and 5.

Table 1. Estimates of sea otter population size from western Prince William Sound, 1993-2009, based on aerial surveys methods of Bodkin and Udevitz (1993).

Year	*Estimated population size*	**Standard error**
1993	2054	698
1994	2228	356
1995	2185	225
1996	2180	218
1997	2341	202
1998	3119	494
1999	2475	381
2000	2658	294
2002	1849	334
2003	2631	400
2004	2704	315
2005	2751	311
2007	2380	372
2008	3609	635
2009	3958	653

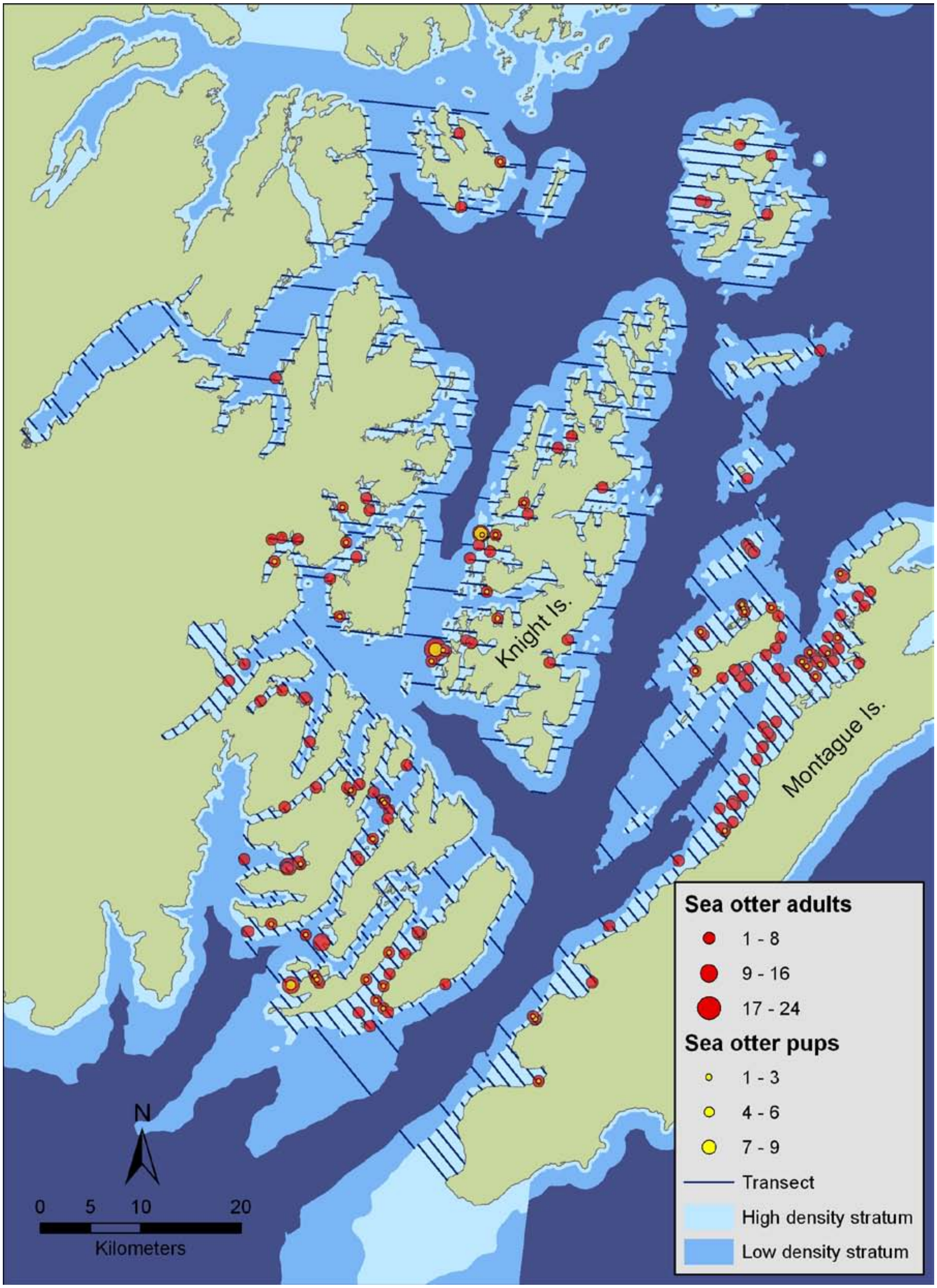

Figure 4. Distribution and relative abundance of sea otters observed along transects surveyed in 2008 in WPWS.

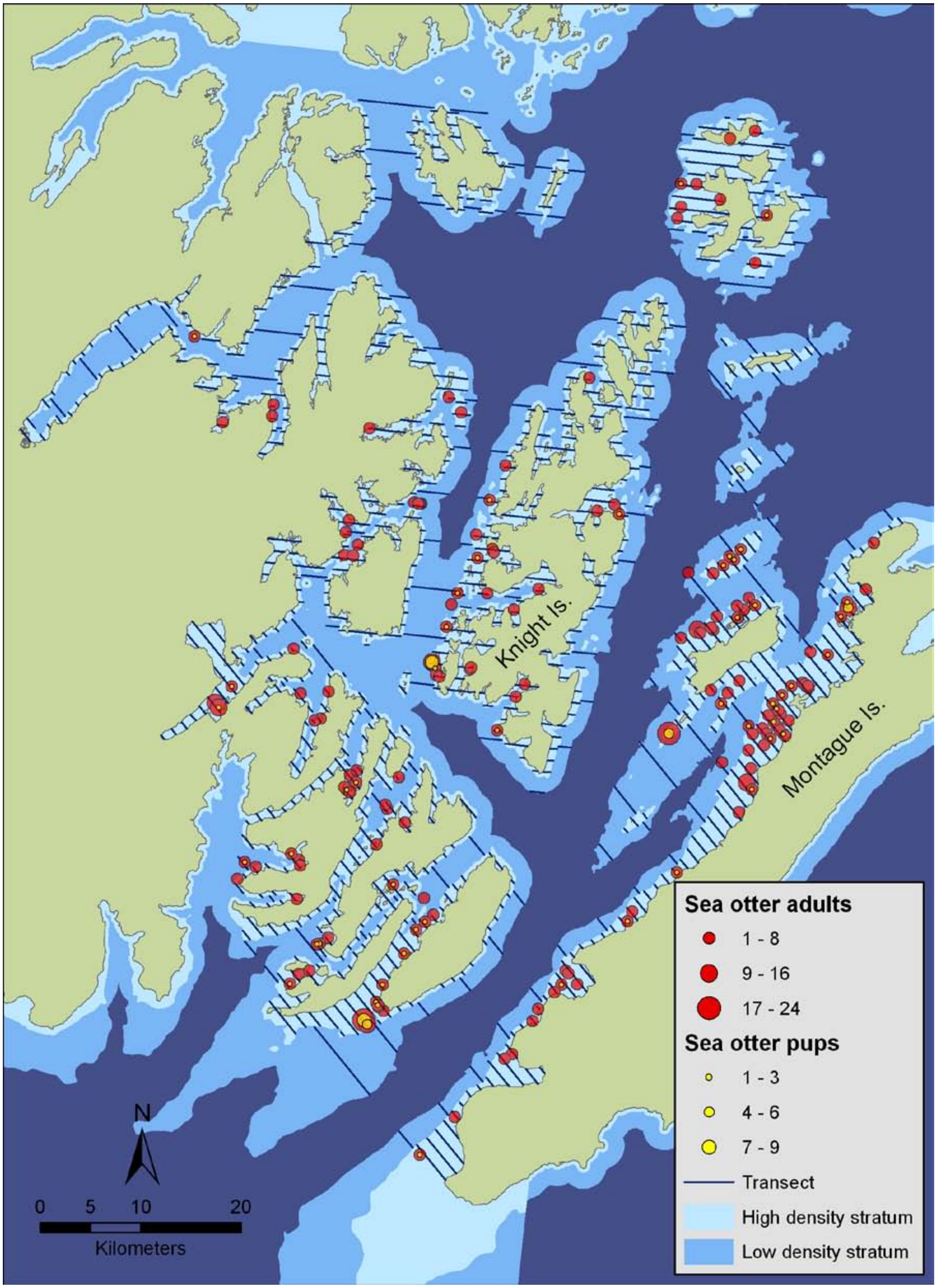

Figure 5. Distribution and relative abundance of sea otters observed along transects surveyed in 2009 in WPWS.

Montague Island (unoiled): We estimated a population size of 310 (se = 62) sea otters at our Montague Island survey area in 2009. At Montague Island there has been a trend toward increasing sea otter abundance, with a non-significant average annual increase of about 1% (Figure 6, Table 2). The distribution of sea otters at Montague Island is presented in Figures 8 and 9.

At Montague Island inter-annual variation has been high, particularly when considering years 2002, 2005, and 2009. This variation may be attributed to the relatively small area being surveyed and potential movement of animals from nearby Green Island, which borders the Montague intensive study area as well as SW along Montague Is (Figures 8 & 9).

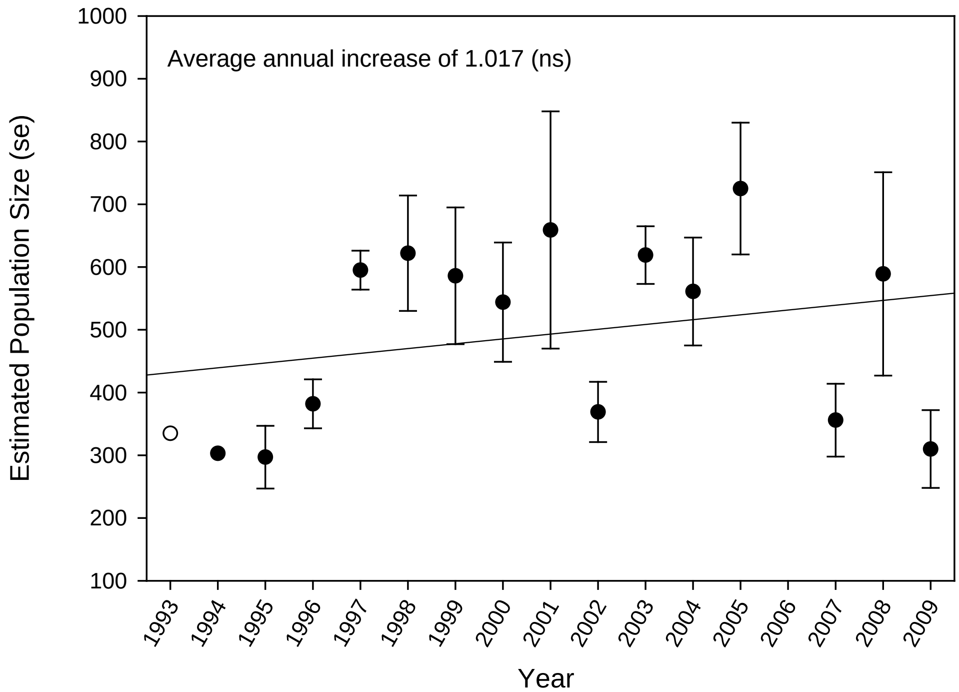

Figure 6. Sea otter population trend at Montague Island, Prince William Sound, 1993-2009. Line is linear regression fitted to all points, bars equal ± one SE. ns = non-significant.

Table 2. Estimates of sea otter population size from Montague Island, Prince William Sound 1993-2009, based on aerial survey methods of Bodkin and Udevitz (1993). No error terms were estimated in 1993 or 1994. N = number of replicate surveys flown.

Year (N)	***Estimated population size***	**Standard error**
1993	335	N/A
1994	303	N/A
1995 (5)	297	50
1996 (5)	382	39
1997 (5)	595	31
1998 (5)	622	92
1999 (5)	586	109
2000 (5)	544	95
2001 (4)	659	189
2002 (5)	369	48
2003 (4)	619	46
2004 (3)	561	86
2005 (3)	725	105
2007 (3)	356	58
2008 (4)	589	162
2009 (2)	310	62

<u>Knight Island (oiled):</u> We estimated a population size of 116 (se = 19) sea otters at the Knight Island survey area in 2009, 98 (se = 24) in 2008, and 71 (se = 14) in 2007. Between 1993 and 2001, the sea otter population size at northern Knight Island remained constant, with an average abundance of 78 (se = 2.1) (Figure 7, Table 3), but apparently declined abruptly between 2001 and 2002. In 2004, we began detecting an increasing trend at Knight Island that extends to 2009. Since 2003, the average annual increase has been about 25%, increasing from 26 in 2003 to 116 in 2009 (Figure 7, Table 3).

Table 3. Estimates of sea otter population size from Northern Knight Island, Prince William Sound, 1993-2009, based on aerial survey methods of Bodkin and Udevitz (1993). No error terms were estimated in 1993 or 1994.

Year	***Estimated population size***	**Standard error**
1993	75	N/A
1994	78	N/A
1995 (5)	89	22
1996 (5)	65	13
1997 (5)	76	19
1998 (5)	76	16
1999 (5)	81	15
2000 (4)	79	6
2001(4)	79	20
2002 (5)	38	11
2003 (5)	26	8
2004 (4)	54	17
2005 (3)	37	14
2007 (3)	71	14
2008 (5)	98	24
2009 (4)	116	19

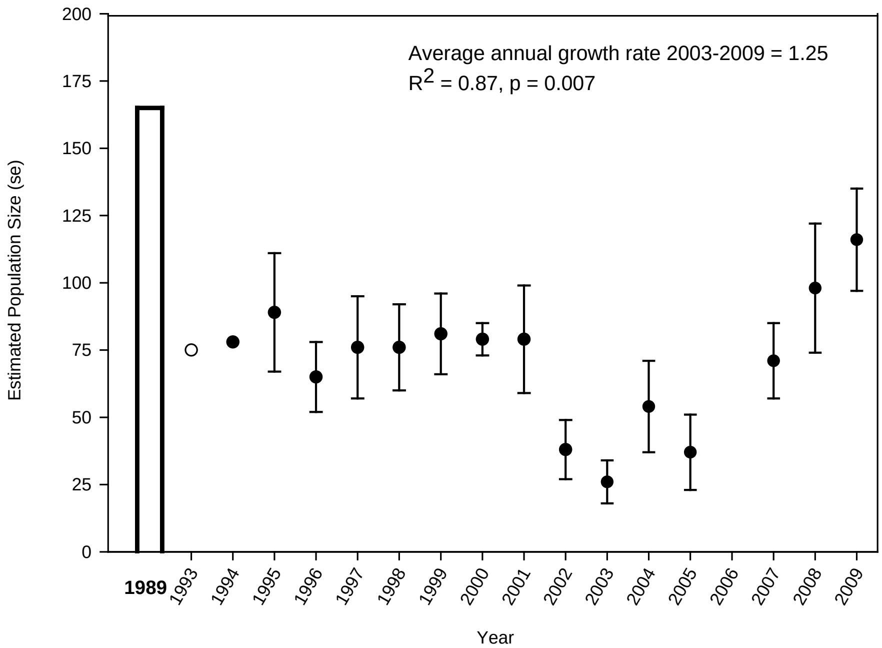

Figure 7. Sea otter population trends at the northern Knight Island, Prince William Sound study area, 1993-2009. The 1989 estimate (165) is the number of sea otters that were captured live (and taken to rescue centers) or recovered as carcasses during March and April of 1989 from the northern Knight Island area where aerial surveys were conducted from 1993-2009. This number does not include animals that survived or those that died but were not recovered in this area. It may include animals that died elsewhere but were recovered here. The only comparable pre-spill sea otter survey (Pitcher 1975) counted about 250 sea otters in this area in 1973.

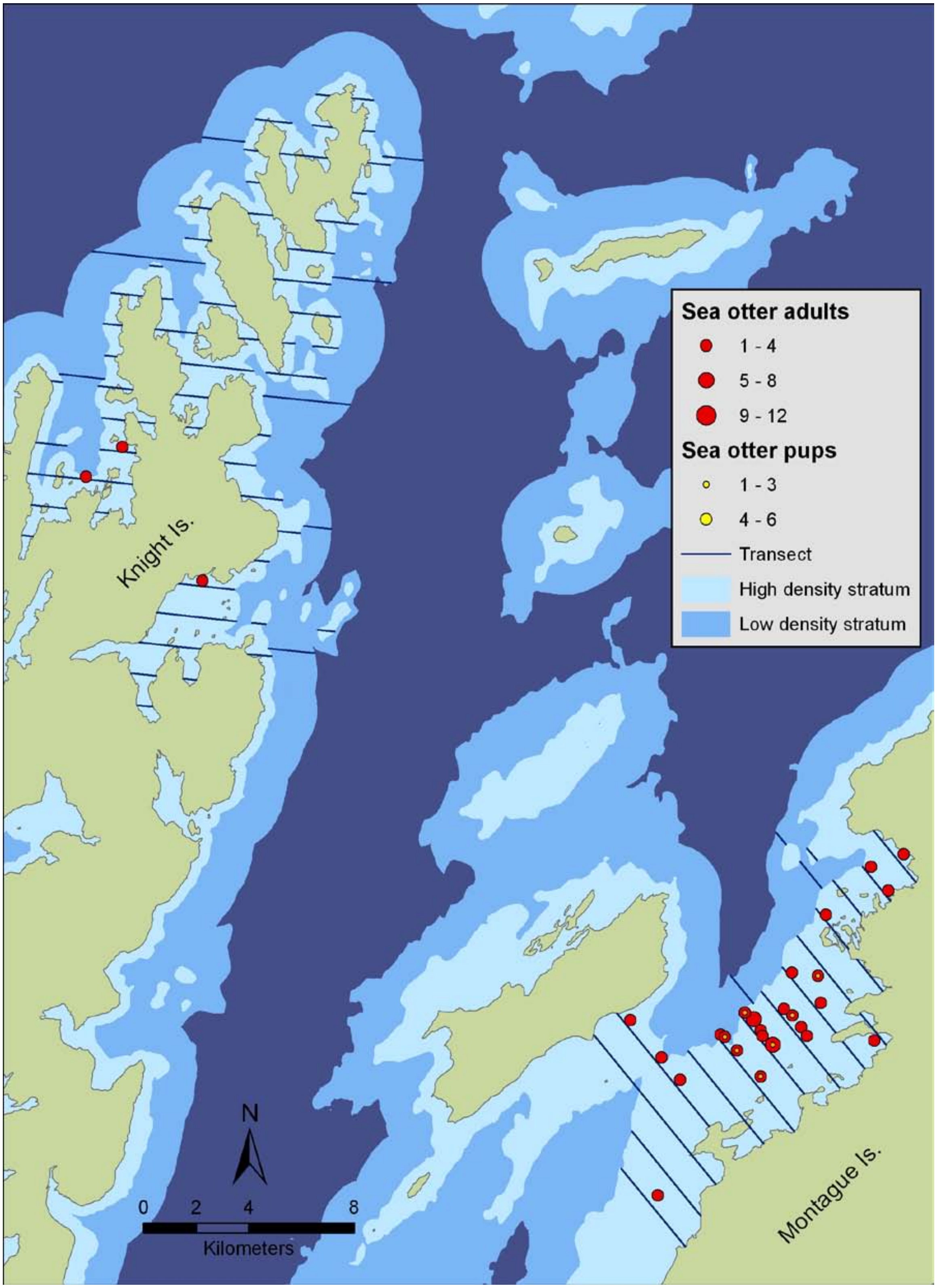

Figure 8. Sea otter distribution and relative abundance at Montague and northern Knight Island, PWS, 2008. Data from one replicate survey only.

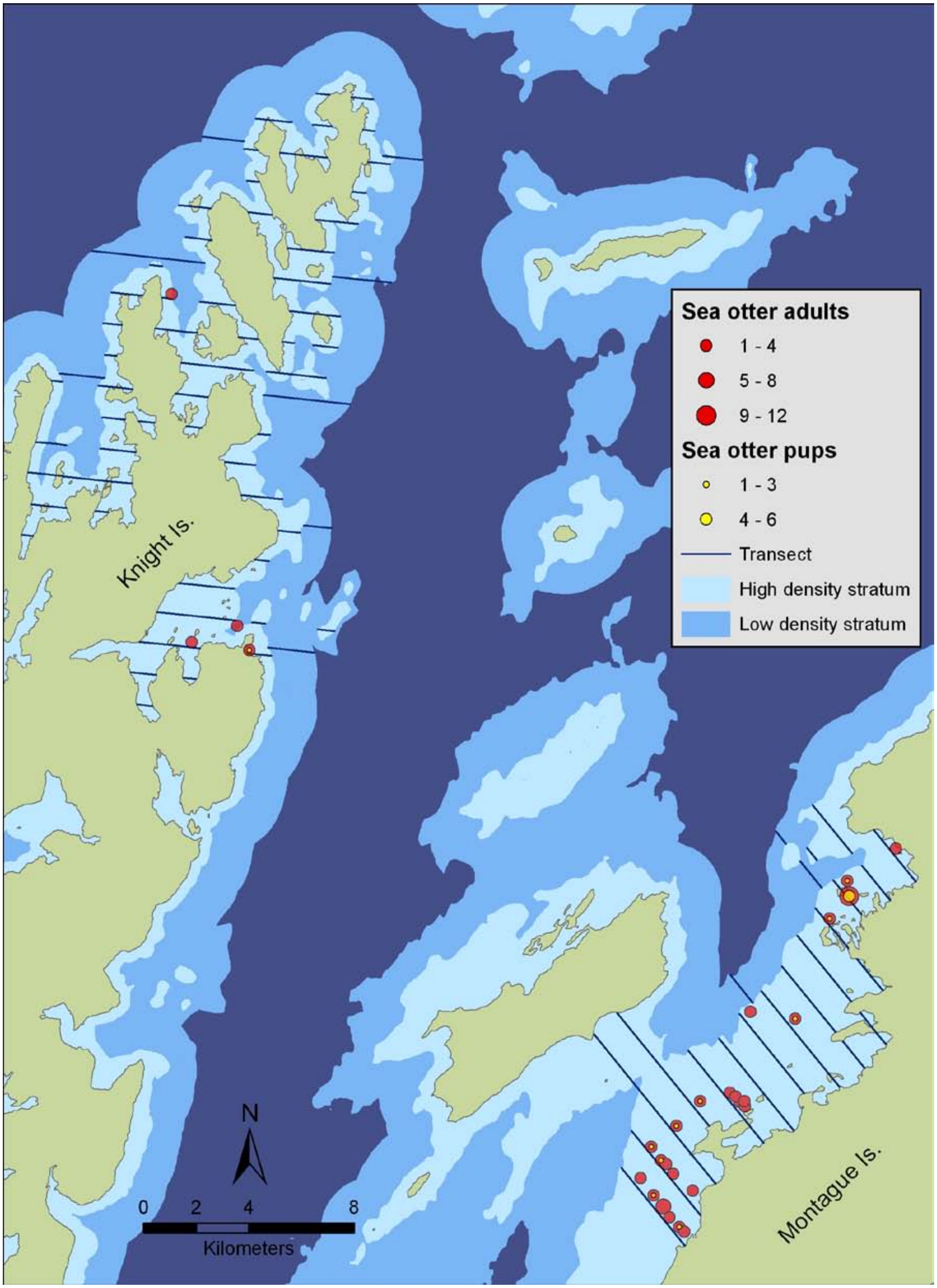

Figure 9. Sea otter distribution and relative abundance at NW Montague and northern Knight Island, PWS, 2009. Data from one replicate survey only.

Discussion

The general pattern of sea otter abundance in WPWS is significantly positive and consistent over the 17 year period from 1993-2009. The two most recent estimates represent an increase of about 1,500-2,000 animals since 1993, and we interpret this as evidence of recovery from the spill at the scale of WPWS. Acute spill related mortality estimates for WPWS range from 750 (Garshelis 1997) to about 2,650 (Garrott et al. 1993). If the present estimates reflect recovery from the EVOS, it would appear that the higher estimate provided by Garrott et al. (1993) may be the more accurate.

The distribution of sea otters across the WPWS survey area has remained relatively stable among years. The general distribution represented in Figures 4 and 5 for 2008 and 2009 is similar among other survey years. This likely reflects the small home ranges resulting from high fidelity to specific resting and foraging areas exhibited by sea otters. Although capable of movements on the order of 100 km, the annual home ranges of adult sea otters generally include less than 20 km of shore and range from a few, to a few tens of km^2 (Riedman and Estes 1991, Estes et al. 2008). These limited movements may in part be responsible for the protracted recovery period exhibited by sea otters following the EVOS. Had otters exhibited greater movements, then perhaps recovery would have been facilitated more rapidly through immigration of individuals from outside the spill-affected area. Alternatively, if the presence of lingering oil in nearshore areas (Petersen et al. 2003, Short et al. 2004, 2006) either dissuades potential immigrants, or results in reduced survival (Monson et al. 2000) in the spill area, then perhaps the process of recovery from events such as this oil spill may be independent of animal movements.

The trend toward increasing abundance at Montague Island is consistent with the increasing trend observed in the larger spill area of WPWS, although at a reduced rate. It is also consistent in representing a population that was not affected by the 1989 oil spill, and thus not expected to attain the magnitude of increase observed in the neighboring spill area where mortality estimates were high and recovery was expected.

The estimates of population size at Montague Island exhibit high variation among years (Table 2), which may be explained by several factors. First, the survey area is relatively small (< 100 km^2), allowing movements of sea otters into and out of the survey area over short time intervals to affect estimates. Second, there is relatively high connectivity through shallow habitat, north to Green Island and southwest along Montague Island (Figure 2) that would facilitate movements at the local scale. Third, the Montague Island study area supports a summer commercial fishery for hatchery raised salmon that in some years coincides with our survey. This latter effect was particularly evident in 2009 when, for the first time since 1993, a gill net fishery occurred, as compared to prior years when the fishery was exclusively conducted by purse seiners. The gill net fishery consisted of dozens of vessels with nets set for extended periods in nearshore waters over a large area, whereas the seine fishery was more centrally located and conducted by fewer vessels with less interaction with sea otters. As a result, it appears that sea otters shifted their distribution southwest of our intensive survey area in 2009 (Figures 4, 5 and 8, 9). The relative contribution of movements and disturbance from fisheries to high inter-annual variation in abundance estimates at Montague Island is unknown.

Based on the number of sea otter carcasses recovered and those that were captured alive for rehabilitation in 1989, Dean et al. (2000) estimated a population size in our Knight Island intensive survey area of 165 individuals at the time of the spill. The 1993-2001 mean of 78 represents a reduction of 53% from the pre-spill estimate, and the 2003 estimate of 26 represents an 84% decline from pre-spill, and a 64% decline from the 1993-2001 mean of 78. The cause of delayed recovery through 2001 was likely related to reduced survival, rather than reduced reproduction (Bodkin et al. 2002) with chronic spill effects and continued exposure to lingering oil potentially contributing to delayed recovery (Bodkin et al. 2002).

After 2003, the sea otter population at Knight Island appeared to increase in abundance, with the 2009 estimate of 116 representing an average annual increase of about 25% since 2003 ($r^2 = 0.87$, $p = 0.007$). However, the 2009 estimate remains 30% less than the pre-spill estimate (Figure 9). The only other estimate of sea otter abundance in our northern Knight Island study area came from 1973 when Pitcher (1975) counted about 250 sea otters. Using either the Pitcher (1975) data point, or the Dean eat al. (2000) data point suggests that sea otters at Knight Island in 2009 remain below potential recovery endpoints.

However, we interpret the significant increasing trend in sea otter abundance at northern Knight Island to indicate progress toward recovery from the 1989 EVOS. This area of intensive study was selected in the years following the spill in recognition of the severity of oiling and sea otter mortality that approached 90% in some areas (Bodkin and Udevitz 1994). An assumption inherent in this selection was that when recovery was evident in those areas most severely affected, it may be reasonable to assume recovery has occurred or is in progress in less impacted areas. Although our 2009 estimate of abundance at Knight Island remains below the estimate of pre-spill abundance (Dean et al. 2000), the highly significant increasing trend since 2003 results in 95% confidence intervals (79-153) for a population size in 2009 that is only slightly less than the pre-spill estimate of 165 animals.

Conclusion

The endpoints for considering sea otter populations recovered from the *Exxon Valdez* spill include attainment of pre-spill levels of otter abundance. Because accurate estimates of abundance prior to the spill are not available at most spatial scales, defining a single numerical recovery endpoint was not possible. Bodkin et al. (2002) described the process toward recovery at the scale of WPWS, as population estimates that were increasing significantly and that approximated the minimum lost estimate of 750 provided by Garshelis (1997). That trend in WPWS has continued and in 2009, the estimate was approximately 2,000 more than the first post spill estimate and about 650 animals less than the PWS acute mortality estimate provided by Garrott et al. (1993). We interpret this increase as continued progress toward recovery that eventually may best be defined as the population size reaches an asymptote. Dean et al. (2000) provided a conservative, yet compelling estimate of pre-spill abundance for a heavily impacted area near the spill site at northern Knight Island. Since 2003 we have seen significant increases in abundance in this area that we interpret as progress toward recovery. In this case, we would infer recovery when the northern Knight population, currently at 116, approximates the 165 estimated pre-spill population size (Dean et al. 2000), If similar rates of increase continue, northern Knight Island may achieve pre-spill sea otter abundance within the next 2-4 years.

Acknowledgements
This work was supported by the Exxon Valdez Oil Spill Trustee Council and the USGS Alaska Science Center. We recognize the significant contributions by Patrick Kearney with the Aviation Management Division of the US Department of Interior for his dedication and skill in piloting the surveys reported here. We also recognize the reviews of this report by E. Beever, D. Burn, K Oakley and two anonymous reviewers.

Literature cited

Ballachey, B.E., J.L. Bodkin and A.R. DeGange. 1994. An overview of sea otter studies. *in* T. Loughlin editor. Marine mammals and the Exxon Valdez. Academic Press. San Diego, CA pages 47-59.

Ballachey B.E., J.L. Bodkin, S. Howlin, A.M. Doroff and A.H. Rebar. 2003. Correlates to survival of juvenile sea otters in Prince William Sound, Alaska. Canadian J. Zoology 81:1494-1510.

Bodkin, J.L. and M.S. Udevitz. 1994. An intersection model for estimating sea otter mortality along the Kenai Peninsula. Pages 81-95 *in* T. R. Loughlin, editor. Marine mammals and the *Exxon Valdez*. Academic Press. San Diego, California, USA.

Bodkin, J.L.and M.S. Udevitz. 1999. An aerial survey method to estimate sea otter abundance. Pages 13-26 *in* G.W. Garner, S.C. Amstrup, J.L. Laake, B.J.F. Manly, L.L. McDonald, and D.G. Robertson, editors. Marine mammal survey and assessment methods. AA Balkema, Rotterdam, Netherlands.

Burn, D.M. 1994. Boat-based population surveys of sea otters in Prince William Sound. Pages 61-80 *in* T.R. Loughlin, editor. Marine Mammals and the *Exxon Valdez*. Acedemic Press, San Diego.

Dean, T.A., J.L. Bodkin, A.K. Fukuyama, S.C. Jewett, D.H. Monson, C.E. O'Clair and G.R. VanBlaricom. 2002. Food limitation and the recovery of sea otters following the 'Exxon Valdez' oil spill. Marine Ecology Progress Series 241:255-270.

Dean, T.A., J.L. Bodkin, S.C. Jewett, D.H. Monson and D. Jung. 2000. Changes in sea urchins following a reduction in sea otter density as a result of the *Exxon Valdez* oil spill. Marine Ecology Progress Series 199:281-291.

Estes, J.A., J.L. Bodkin and M Ben-David. 2008. Marine Otters. In W.F. Perrin, B. Wursig, J.G.M. Thewissen and C.R. Crumly, editors. Encyclopedia of Marine Mammals, 2nd Edition. Academic Press.

Garrott, R.A., L.L Eberhardt and D.M. Burn. 1993. Mortality of sea otters in Prince William Sound following the *Exxon Valdez* oil spill. Marine Mammal Science 9(4):343-359.

Garshelis, D.L. 1997. Sea otter mortality estimated from carcasses collected after the *Exxon Valdez* oil spill. Conservation Biology 11(4):905-916.

Peterson, C.H. 2000. The *Exxon Valdez* oil spill in Alaska: acute, indirect, and chronic effects on the ecosystem. Advances in Marine Biology 39:1-103.

Peterson, C.H., S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey and D.B. Irons. 2003. Long-term ecosystem response to the *Exxon Valdez* oil spill. Science 302:2082-2086.

Pitcher, K.W. 1975. Distribution and Abundance of Sea Otters, Stellar Sea Lions, and Harbor Seals in Prince William Sound, Alaska. Alaska Dept. of Fish and Game, Anchorage, AK. Unpublished report.

Riedman, M.L. and J.A. Estes. 1990. The sea otter (*Enhydra lutris*): Behavior, ecology, and natural history. U.S. Fish Wildl. Serv. Biological Report 90(14).

Short, J.W., M.R. Lindeberg, P.M. Harris, J.M. Maselko, J.J. Pela and S.D. Rice. 2004. Estimate of oil persisting on the beaches of Prince William Sound 12 years after the *Exxon Valdez* oil spill. Environmental Science and Technology 38(1):19-25.

Short, J.W., J.M. Maselko, M.R. Lindeberg, P.M. Harris and S.D. Rice. 2006. Vertical distribution and probability of encountering intertidal *Exxon Valdez* oil on shorelines of three embayments within Prince William Sound, Alaska. Environ. Sci. Technol. 40:3723-3729.

Udevitz, M.S., B.E. Ballachey and D.L. Bruden. 1996. A population model for sea otters in western Prince William Sound. *Exxon Valdez* oil spill restoration project final report (restoration project 93043-3), Natl. Biol. Serv., Anchorage, AK. 34pp.