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Recovery Potential Assessment for Sea Otters (*Enhydra lutris*) in Canada

Évaluation du potentiel de rétablissement de la loutre de mer (*Enhydra lutris*) au Canada

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ABSTRACT

Sea otters were extirpated from British Columbia by 1929. In an effort to re-establish the species in Canada, 89 sea otters from Alaska were re-introduced to Checleset Bay, Vancouver Island between 1969 and 1972. The most recent population surveys indicate that, based on direct counts the B.C. sea otter population includes a minimum of 3,180 sea otters (surveys 2001 to 2004) (Nichol *et al.* 2005). The population occurs along the west coast of Vancouver Island and on a small section of the central B.C. coast although most of the population (~ 85%) occurs along the west coast of Vancouver Island. Population growth has been positive, at 19.1% per year on Vancouver Island between 1977 and 1995 but slowed to 8.0% per year (1995 to 2004) for an overall average annual rate of 15.6% per year between 1977 and 2004. Growth may have slowed along Vancouver Island as parts of the range have reach equilibrium densities. On the central B.C. coast growth has average 12.4% per year (1990 to 2004). Based on historical information from the maritime fur trade and on modeling of available habitat the population in B.C. likely occupies at most 25 to 33% of its historic range. Coast –wide sea otter habitat carrying capacity estimates of 14,844 (9,798-20,769, 95% CI) for optimal habitat and 52,199 (48,672-59,018, 95% CI) based on otters per kilometer of shoreline suggest that at its current size the Canadian sea otter population is far below carrying capacity.

Population growth and range expansion are inter-related in this species. Sea otters are non-migratory and occupy small overlapping home ranges. Range expansion occurs as areas of occupation near carrying capacity. Male sea otters then move from the periphery of the occupied range into adjacent habitat. Females subsequently occupy the new habitat once the males have moved on. Therefore given this inter-relationship it follows that increasing the geographic range of the species is expected to result in both a larger population and one in which the risk from human activities is reduced. An interim recovery target is therefore to continue the range expansion of the species in British Columbia.

Estimates of allowable harm that would not jeopardize recovery were presented based on the effect of mortality on the time to achieve recovery in two geographic areas that encompass the current range on west coast Vancouver Island and on the central B.C. coast. The resulting estimates, 40 to 90 animals per year on Vancouver Island and 20 to 25 animals per year on the central B.C. coast were predicted to delay recovery by ≤ 10% to a target level in each area of 80 to 95% of the habitat-based carrying capacity estimate. The target levels ≥ 80% of carrying capacity were chosen to reflect the inter-relationship between population growth and range expansion. The assumptions made to calculate these estimates and the uncertainties of some of the model parameters, in particular the habitat-based carrying capacity estimates for the central coast section are discussed. Should a directed take be considered for the B.C. population, harvest should be deferred on the central B.C. coast because of the uncertainties and assumption and because that portion of the population is very small. For west coast Vancouver Island, the lower estimate would be precautionary should a directed take be considered.

RÉSUMÉ

Les loutres de mer sont disparues de la Colombie-Britannique depuis 1929. Dans le cadre des efforts visant à rétablir l'espèce au Canada, 89 loutres de mer de l'Alaska ont été réintroduites dans la baie Checleset de l'île de Vancouver, entre 1969 et 1972. Le plus récent relevé de la population révèle, selon un dénombrement direct, que la population de loutres de mer de C. B. comprendrait au moins 3 180 individus (relevés de 2001 à 2004) (Nichol et coll., 2005). On trouve des loutres sur une petite section de la côte centrale de la province, même si la plus grande partie de la population (~ 85 %) vit le long de la côte ouest de l'île de Vancouver. La croissance de la population a été positive, s'établissant à 19,1 % par année dans l'île de Vancouver, entre 1977 et 1995, mais elle a ralenti à 8,0 % par année (1995 à 2004) par la suite, ce qui représente un taux annuel de 15,6 % par année entre 1977 et 2004. Le ralentissement le long le l'île de Vancouver serait attribuable à ce qu'un équilibre a été atteint dans certaines parties sur le plan de la densité. Sur la côte centrale de la C. B., la croissance se situe en moyenne à 12,4 % par année (1990 à 2004). Selon les données historiques du commerce maritime de la fourrure et les modèles de l'habitat disponible, la population de la C. B. occupe vraisemblablement tout au plus de 25 à 33 % de son aire historique. Les estimations de la capacité de charge de l'habitat de la loutre de mer à l'échelle de la côte, de 14 844 (9 798-20 769, IC 95 %) pour un habitat optimal et de 52 199 (48 672-59 018, IC 95 %) en fonction du nombre de loutres par kilomètre de côte, semblent indiquer qu'à sa taille actuelle, la population de loutres de mer canadiennes est bien inférieure à la capacité de charge.

La croissance de la population de cette espèce et l'expansion de son aire sont interreliées. Les loutres de mer ne sont pas migratrices et occupent de petits territoires qui chevauchent. Il y a expansion du territoire lorsque la capacité de charge est atteinte dans une zone d'occupation. Les loutres mâles se déplacent alors en périphérie de l'aire occupée vers l'habitat adjacent. Les femelles occupent par la suite un nouvel habitat quand les mâles se sont déplacés. Par conséquent, compte tenu de cette interrelation, il en découle que l'élargissement de l'aire de répartition géographique de l'espèce devrait donner lieu à la fois à un accroissement de la population et à une zone où les risques d'activités anthropiques sont moindres. La cible de rétablissement provisoire consiste donc à poursuivre l'expansion de l'aire de l'espèce en Colombie-Britannique.

L'estimation des dommages admissibles qui ne nuiraient pas au rétablissement est présentée en tenant compte de l'effet de la mortalité sur le temps requis pour arriver au rétablissement dans deux zones géographiques qui englobent l'aire actuelle sur la côte ouest de l'île de Vancouver et sur la partie centrale de la côte de la C. B. Les estimations qui en résultent, soit de 40 à 90 animaux par année dans l'île de Vancouver et de 20 à 25 loutres par année sur la côte centrale de la province, retarderaient le rétablissement de ≤ 10 % pour un niveau cible dans chaque zone de 80 à 95 % de la capacité de charge estimée de l'habitat. Des niveaux cibles de ≥ 80 % de la capacité de charge ont été choisis pour bien tenir compte de l'interrelation entre la croissance de la population et l'expansion de l'aire. Les hypothèses posées pour faire ces calculs et l'incertitude associée à certains des paramètres des modèles, en particulier l'estimation de la capacité de charge de l'habitat pour la côte centrale de la C. B., sont examinées. Si l'on envisageait des prélèvements dirigés au sein de la population de la C. B., ils devraient être retardés dans la partie de la côte centrale de la province à cause des incertitudes et des hypothèses et, également, parce que cette portion de la population est très restreinte. Pour la côte ouest de l'île de Vancouver, on devrait, par souci de prudence, tenir compte de l'estimation la plus basse si l'on envisage une chasse dirigée.

INTRODUCTION

The sea otter is listed as Threatened in Canada under the Species at Risk Act (SARA). Throughout its range in the North Pacific the species was driven almost to extinction as a result of the maritime fur trade by Russian, European, and American traders with aboriginal peoples that commenced in the mid 1700s and continued through the 1850s. By the 1850s sea otters were likely ecologically extinct, at least in British Columbia (Watson 1993). Continued opportunistic hunting driven by the market value of pelts (which increased as the species declined) led finally to extirpation of the species from British Columbia by 1929 (Cowan and Guiguet 1960). In an effort to re-establish the species in British Columbia, 89 sea otters were reintroduced in three translocation efforts to Checleset Bay, Vancouver Island from Alaska between 1969 and 1972. The population is increasing numerically and in terms of range. The most recent population surveys (2001 to 2004) indicate a minimum population size of 3,180 otters (Nichol *et al.* 2005). As required under SARA, a Recovery Strategy (2003) and a Recovery Action Plan were drafted to guide recovery of the sea otter in Canada. At the time these documents were developed, neither recovery potential nor allowable harm assessments were included. The objectives of this paper are to present recovery targets, estimate time to recovery and the impact of additional sources of human-caused mortality on time to achieve recovery.

BIOLOGY AND LIFE HISTORY

The sea otter, *Enhydra lutris*, is the only member of the genus *Enhydra.* Three subspecies are recognized, *Enhydra lutris kenyoni* ranged historically from Oregon to the Aleutian Islands; *Enhydra lutris nereis,* the southern sea otter, occurs along the California coast; and *Enhydra lutris lutris* ranges from the Kuril Islands to the Kamchatka Peninsula and the Commander Islands in Russia. *Enhydra lutris kenyoni* occurs in British Columbia.

Unlike other marine mammals, sea otters have little body fat to provide insulation. Instead they maintain an exceptionally high metabolic rate and rely on a layer of air trapped in their dense fur for insulation. Sea otters groom frequently to maintain the integrity of their fur and its ability to hold a layer of trapped air for insulation (reviewed in Riedman and Estes 1990).

Sea otters are sexually dimorphic. Adult males can reach weights of 46kg and total lengths of 148cm, whereas adult females can grow to 36kg and reach lengths of 140cm. At birth pups weigh 1.7-2.3 kg and are up to 60cm in total length (Bodkin 2003). Female sea otters reach sexual maturity at 2 to 5 years (Bodkin *et al.* 1993; Jameson and Johnson 1993) with all females reproductive by age 5 (Monson *et al.* 2000a). Males reproduce at 5 to 6 years of age, although they may be sexually mature earlier (Riedman and Estes 1990: Bodkin *et al.* 1993). Females have a higher survival rate than males (Siniff and Ralls 1991) and live 15 to 20 years, whereas males live only 10 to 15 years (Riedman and Estes 1990). Although mating and pupping can occur year-round, distinct peaks in pupping in spring are noted in some populations including British Columbia (Watson 1993; Bodkin 2003). Sea otters are polygynous with males forming pair bonds consecutively with several females. Females produce a single pup at approximately 1-year intervals and the pup remains dependent on its mother for 6 to 8 months after which it is weaned (Payne and Jameson 1984; Siniff and Ralls 1991; Bodkin *et al.* 1993; Jameson and Johnson 1993).

Sea otters are non migratory and exhibit considerable site fidelity, although seasonal movements and occasional long distance movements of individuals may occur (Garshelis 1983; Jameson 1989). Sea otters occupy relatively small overlapping home ranges varying in size from a few to 10s of kilometres of coastline (Loughlin 1980; Garshelis *et al.* 1984; Jameson 1989). Within their home ranges, sea otters aggregate to rest in floating groups, called rafts that can include over 100 individuals. Sea otters segregate by sex such that there are male rafts and female rafts that occupy spatially separate areas.

Ecological Role

The sea otter is a nearshore species feeding primarily on benthic invertebrates, which it obtains by diving to the sea floor. Most foraging dives are in less than 40m depths (Bodkin et al. 2004). The sea otter is recognized as a keystone species contributing significantly to the structure and function of nearshore benthic communities and upon the life history of their invertebrate prey (Estes and Palmisano 1974; Estes *et al.* 2005). These interactions also have implications for many invertebrate fisheries.

By foraging on herbivorous invertebrates, particularly sea urchins, sea otters reduce grazing pressure. This allows kelp to grow, thereby altering the community from one dominated by grazers with little kelp to one that supports kelp and invertebrates as well as a greater abundance and diversity of fish species (Breen *et al.* 1982; Watson 1993; Estes and Duggins 1995; Reisewitz *et al*. 2006). Research in the Aleutian Islands indicates that communities dominated by sea otters are up to 2 to 3 times more productive than systems without sea otters because of the kelp-derived carbon (Duggins *et al.* 1989). Secondary effects of sea otter predation may include the following. Predation pressure may restrict some species of herbivorous invertebrates to refugial habitat (to avoid predation) thereby concentrating individuals into localized patches (Hines and Pearse 1982). Since many invertebrates are broadcast spawners, aggregating may enhance mixing of gametes and thus increase fertilization rates despite overall low densities of the adults a result of otter predation (Watson 2000). Furthermore kelp beds may help to entrain larvae, keeping them in suitable habitat until they settle, thereby improving settlement success.

The extirpation of sea otters from much of their range resulted in a high abundance of invertebrates in the absence of their key predator. This factor, along with the development of trade markets, and the invention of SCUBA allowed for the rise of many commercial invertebrate fisheries, (Estes and VanBlaricom 1985; Watson and Smith 1996; Watson 2000; Bodkin 2003). While not all declines in abundance that have occurred in some invertebrate fisheries can be attributed to sea otters, it is evident that many will not be able to persist once sea otters occupy the same areas (Watson and Smith 1996). Sea otters can be expected to reduce abundance and size of their prey species such that a fishery may not be sustainable but there is no evidence, that recovering sea otter populations will or have caused extirpation of any invertebrate species.

Habitat

The extent of sea otter habitat is defined by their ability to dive to the sea floor for food. Most foraging occurs in depths of 40m or less, although otters are capable of foraging to depths of 100m (Riedman and Estes 1990; Bodkin *et al.* 2004). Sea otters occur within 1-2 km of shore but can also be abundant far from shore in areas where water is less than 40m deep (Riedman and Estes 1990). When present, kelp beds are often used habitually as rafting sites (Loughlin 1980; Jameson 1989). Kelp beds are also used for foraging and are important, though not essential, habitat components. Soft-bottom communities that support clam species are also very important foraging habitat and can sustain high densities of otters (Kvitek *et al.* 1992; Kvitek *et al.* 1993).

In British Columbia, sea otters occupy exposed coastal areas with extensive rocky reefs and associated shallow depths along the west coast of Vancouver Island and the central B.C. coast, but weather and sea conditions may influence habitat use. Sea otters tend to occur in these exposed areas during periods of calm weather, but within their home ranges, may aggregate inshore during inclement weather, particularly during winter (Morris *et al.* 1981; Watson 1993). As the population grows and the range expands, it is likely that characteristics of the habitat used by sea otters will broaden.

Critical Habitat has not yet been identified or estimated for this species. The draft Sea Otter Recovery Strategy and Action Plan both list a number of studies that may assist in identifying critical components of their habitat. These include identification of winter habitat, studies to identify rafting and foraging habitat characteristics, and tagging studies to estimate home range and habitat use patterns of individuals.

The concept of a residence as defined in SARA is unlikely to be applicable to sea otters.

PHASE I: Assess Current Species Status

Abundance, Trends and Distribution

Population range expansion and population growth are related in sea otter populations. Since sea otters are non-migratory and occupy relatively small over-lapping home ranges, expansion occurs when occupied areas near equilibrium and males move *en masse* from the periphery of the occupied range into previously unoccupied habitat. Females gradually occupy the areas vacated by males (Loughlin 1980; Garshelis *et al.* 1984; Wendell *et al.* 1986; Jameson 1989).

Since re-introduction to Checeset Bay, the sea otter population has grown and the range expanded southward and northward along the west coast of Vancouver Island. Sea otters were first reported in the Goose Group Islands on the central B.C. coast in 1989 and were first surveyed there in 1990, 56 otters were found (BC Parks 1995; Watson et al. 1997). The central B.C. coast sea otters appear to be descendents of re-introduced sea otters (DFO unpubl.) and their appearance on the central coast, a considerable distance from the Vancouver Island range, likely reflects early movement of released animals rather than natural range expansion. The occupied range as of 2004 is presented in Figure 1.

Surveys in 2001 resulted in a count of 2,673 otters along the Vancouver Island coast and 507 on the central British Columbia coast for a total of 3,180 otters (Nichol *et al*. 2005). Surveys made in 2002, 2003 and 2004, resulted in similar counts suggesting little growth in population since 2001 (Nichol *et al.* 2005). Sea otter population surveys are direct counts of observed sea otters and are minimum estimates that provide an index of population abundance (Nichol *et al.* 2005). On Vancouver Island the population growth rate averaged 15.6% per year (1977 to 2004) based on a simple log-linear regression of counts but a piece-wise regression which allows for an inflection in the log-linear trend showed that the initial rapid growth of 19.1% per year from 1977 to 1995 (near physiological maximum) may have slowed to 8.0% per year from 1995 to 2004. This decline in the growth rate likely reflects parts of the population near the centre of the range along Vancouver Island reaching equilibrium densities. On the central British Columbia coast, the population growth rate averaged12.4% per year between 1990 and 2004 a rate that seems low for a population expanding into areas where prey are not yet limiting and there may be greater inter-survey variability in this area obscuring the trend and/or unknown sources of mortality (Nichol *et al.* 2005). **Table 1** presents recent estimates of abundance for other populations in North America.

High population growth rates near the physiological maximum of the species (17 to 20% per year) were typical in the early years following successful establishment in reintroduced populations in Washington, southeast Alaska as well as B.C. (Estes 1990). These rates likely reflect the increased size and abundance of prey that developed in the long absence of sea otters following extirpation (Bodkin *et al*. 1999) but these rates were not typical of recovering remnant populations (e.g. western Alaska, central Alaska, and California). Significant differences have been noted between the growth rates of remnant and translocated populations. Recovery rates among remnant populations were significantly lower than those of translocated population and have included periods of decline (Bodkin *et al*. 1999). Continued illegal harvest of these populations after 1911 may have been one factor (Bodkin *et al*. 1999). Presently, recovery of the sea otter population in Prince William Sound as a result of EVOS in 1989 has been relatively slow and the impact of habitat degradation may be a factor (Bodkin *et al*. 2002).

Although the sea otter population in British Columbia has increased significantly from the 89 animals released into Checelset Bay, the size of the population is still quite small compared to recent estimates made of habitat carrying capacity and also from accounts from the maritime fur trade that indicate the magnitude of the harvest and therefore the population that must have occurred to sustain such a harvest.

Maritime fur trade

Although it is difficult to estimate the proportion of total annual pelts from the Pacific Northwest that would have come from just B.C. (and not also Washington, Oregon, southeast Alaska and central and western Alaska), it is likely that the annual harvest from B.C. plus SE Alaska was about 10,000 per year for the period 1799 to 1801 (*estimate based on tabulations in* Busch and Gough 1997). By this time the maritime fur trade along the Pacific coast had been underway for 14 years and continued until the 1850s.

Records from surviving 18th Century logbooks and voyage accounts of vessels that visited the Queen Charlotte Islands indicate that between 1787 and 1797 at least 11,000 pelts were landed in the Queen Charlotte Islands alone and the aggregate cargo from the Queen Charlotte Islands of 4 ships in 1791 appears to have been 3,759 pelts (tabulated from Dick 2006).

Carrying capacity estimates

Gregr *et al.* (in Press) estimated that the B.C. coast carrying capacity in habitat characterized by a high degree of shoreline complexity similar to that of Checleset Bay and Kyuquot Sound would be 14,844 sea otters, (9,798 – 20,769, 95% CI). They noted that this estimate seemed low coast-wide given the historic accounts from the fur trade and they noted further that their model included very little habitat in the Queen Charlotte Islands which seemed incongruent with historical records. They proposed that their habitat model performed well identifying complex habitat similar to Checleset Bay and Kyuquot Sound, habitat common on west coast Vancouver Island, but that other types of habitat that would support sea otters must also exist. Using shoreline length and an estimate of otters per kilometer of shoreline they estimated an upper limit to coast-wide carrying capacity of sea otters, 52,199, (48,672-59,018, 95% CI). This estimate assumes that otter density is independent of habitat type, which is unlikely. At its current population size, however, the B.C. sea otter population would appear to be well below either of these estimates of carrying capacity.

Population Abundance and Distribution Targets

Range expansion is crucial to reduce the population level threat of an oil spill. Sea otter distribution and abundance are highly inter-related because unoccupied habitat is sequentially occupied only as the number of otters in neighbouring areas approaches carrying capacity. Given the relationship between range size and population abundance coupled with the localized movements of individuals, it follows that increasing the geographic range of the species is expected to result in both a larger population and one where the risk of extinction due to human-induced mortality is reduced. Therefore, an interim recovery target for sea otters on the British Columbia coast is to continue the geographic range expansion of the species.

General Time frame to Recovery Target

While it has taken approximately 30 years for the population to expand from Checelset Bay on Vancouver Island to occupy its current range, it is difficult to establish a time frame to recovery in the absence of a quantitative recovery target.

PHASE II. Scope of Human-Induced Mortality

Maximum human-induced mortality

Maximum human induced mortality estimates were made by assessing the impact on the time required for the population to reach a specified population size relative to carrying capacity (Wade 1998). To assess the impact of increased mortality on recovery, a logistic growth model (Pella and Thompson 1969) was used to describe density dependent growth of sea otters on west coast Vancouver Island and in Statistical Areas 6 and 7 using estimates of carrying capacity and maximum net recruitment rate for the B.C. population (Watson *et al.* 1997; Gregr *et al.* (in Press). Numerical values, percentages of carrying capacity in these regions, were selected, as targets for the model. The assessment was then a comparison of the number of years for the population to reach the target in each region when additional annual mortality = 0, versus when additional mortality is > 0.

The following form of the logistic equation was used to describe the population.

$$N_{t+1} = N_t + N_t R_{max}[1-(N_t/K)^{\theta}] - C$$

Where:

N_t = population size at time t,

R_{max} = maximum net recruitment rate,

K = carrying capacity

θ = Theta is an exponent that governs the shape of the growth curve and determines when the density-dependent effect begins.

C = number of animals removed from the population annually. This is mortality above the amount that is occurring now with the present growth rate.

Estimates of Carrying Capacity (K)

From spatial habitat models two estimates of sea otter carrying capacity on the west coast Vancouver Island are 4,887 (95% CI, 3,226-6,837) and 5,123 (95% CI, 3,337-7,104) and from a linear coastline approach is 8,303 (95% CI , 5,424 – 11,633) (**Table 2**) (Gregr *et al*. (in Press). The spatial model results are very similar, therefore 5,000 was used as the point estimate for carrying capacity in presently occupied and as yet unoccupied habitat on west coast Vancouver Island.

Sea otters occur in part of Statistical Area 7, on the central B.C. coast, but northward range expansion seems to be occurring, therefore Statistical Area 6 was used to obtain a northern spatial boundary (DFO unpubl.). Using the spatial habitat model of Gregr *et al.* (in Press), carrying capacity was estimated to be 2,687 (95% CI 1,723 – 3,652) (**Table 2**). The shoreline length derived estimate is too high, reflecting the considerable amount of shoreline in deep inlets in these Statistical Areas (**Figure 2**). Gregr *et al.* (in Press) felt that the habitat model carrying capacity estimate for areas north of Vancouver Island seemed low compared to information available from the maritime fur trade and they discuss the possibility of additional habitat types that may not have been identified by the habitat model. Therefore in this modeling exercise, 2,700 and 3,700 representing the mean and upper 95% confidence interval of the habitat model derived estimate were used.

Initial Population size

The initial population sizes, N_t was set at the first population counts: 1977, Vancouver Island, 70 otters (Bigg and MacAskie 1978), 1990, central B.C. coast, 56, otters (Watson *et al.* 1997).

Maximum Net Productive Rate (R_{max})

Successfully reintroduced sea otter populations have exhibited growth rates of 17-20% in the early years following reintroduction likely as a result of the high abundance of invertebrate prey that developed in the absence of sea otter predation following extirpation. Such high rates of growth are thought to be near R_{max} for the species (Estes 1990). The maximum growth rate estimated from fitting the sea otter survey data from Vancouver Island between 1987 and 1995 to a logistic model was 18.0% per year. The R_{MAX} value was calculated from these data from Vancouver Island because this was a period of rapid growth and consistent survey coverage.

Shape Parameter (θ)

Theta (*θ)* is an exponent that governs the shape of the growth curve and determines when the density-dependent effect begins. The sea otter survey data from Vancouver Island between 1977 and 2004 were fitted to a logistic model and shape was estimated to be 1.0. Gerber *et al.* (2004), fit Washington state sea otter survey data to logistic models and found that the logistic model with theta = 1.0 fit best.

Additional Human Caused Mortality (C)

Values of *C* ranging from 0 to 220 were used, in increments of 10 from 0 to 100 and increments of 20 from 100 to 220.

Target

To assess the effect of increased human-caused mortality, a target was set, as a percentage of the K estimate for each of these areas. The target was set at 80% of carrying capacity, since range expansion and population growth are inter-related such that range expansion occurs only as occupied areas approach carrying capacity.

Criteria for selecting potential acceptable levels of increased mortality

Two criteria were used to select two theoretically acceptable level of additional mortality that would not delay years to the target (YTT) by more than 10% (Wade 1988). They were:

A. An annual mortality that does not delay YTT by more than 10%.

B. An annual mortality that does not delay YTT by more than 10% and that also allows the population to continue to grow to 0.95K.

Model Results

Tables 3 and 4 present the model predictions regarding time to achieve 80% of carrying capacity on west coast Vancouver Island and in Statistical Areas 6 and 7 in the absence of additional human caused mortality. Tables 5 and 6 present the estimates of allowable harm according to the above two criteria.

The actual time for the west coast of Vancouver Island and the central B.C. coast statistical areas 6 and 7 to achieve 80% *K* is likely underestimated by the logistic model. Growth in sea otter populations likely occurs by rapid growth in newly occupied areas which eventually slows as these areas near equilibrium. Subsequent expansion into adjacent habitat is followed by rapid growth there resulting from both reproduction and immigration. The overall effect is likely a stepwise growth pattern and is also likely influenced by the distance from areas at equilibrium to new habitat, rather than the simplistic trajectory predicted by a logistic model. Therefore the time frame to achieve the target on west coast Vancouver Island is better stated as likely to occur within the next five to ten years. The time frame for the central B.C. coast Statistical areas 6 and 7 is less certain than that predicted by the models because the carrying capacity estimate for the area is less certain, the actual growth rate on the central B.C. coast is less certain, and the assumption that range expansion will continue to occur primarily to the north into Statistical area 6 is uncertain.

The levels of allowable harm that are predicted by the logistic model to delay recovery by only 10% are useful for consideration but are dependent on the underlying estimates of habitat carrying capacity and growth rate and the assumption that current levels of mortality will remain constant. B.C. sea otter surveys provide counts that are an index of population size and hence trends in growth. Yet with a sample variance of *CV* 0.07 to 0.12 for sea otter surveys in B.C., long time series of surveys are required to detect growth trends (Gerrodette 1987; Nichol *et al.* 2005). Of course this limitation applies to detection of negative growth trends as well unless they are precipitous. Given the limited ability to detect a population level effect (decline), if a directed take is considered for west coast Vancouver Island, the level should be set at Outcome B (Table 5) to be more precautionary considering these uncertainties.

The number of sea otters on the central B.C. coast is well below 1,000 animals based on surveys in 2004 (Nichol *et al.* 2005). An effective population (N_e) of 500 is considered an important conservation threshold for southern sea otters below which they are considered endangered (USFW 2003). N_e is a concept used in genetics that corresponds to a minimum population size that experiences the same amount of genetic drift and processes of natural selection as the actual population and thus maintains some resilience to environmental stochasticity. Since not all individuals contribute equally to reproduction, the actual population size (N) corresponding to effective population is larger. N_e/N was estimated to be 0.27 for southern sea otters and thus N = 1,850, the threshold for endangered (Ralls *et al.* 1983; Mace and Lande 1991; Ralls *et al.* 1996; USFW 2003). If a directed take is considered for the B.C. population it would be precautionary to defer any take on the central B.C. coast since the number of sea otters there (though not a separate population from west coast Vancouver Island) is well below the level corresponding to N_e = 500,

In a logistic model it is assumed that all individuals contribute equally to reproduction and mortality. However, sea otters are polygynous and the sex ratio of mortality is likely to significantly influence growth. Indeed detailed demographic modeling of the southern sea otter population suggests that survival of adult females is the primary factor responsible for regulating population growth and driving trends in the California sea otter population (Tinker *et al.* 2006). In southeast Alaska the population growth rate has slowed considerably from 18% per year (1969 and 1988) to an average across the region of 4.7% per year (1988 to 2003) despite ample amounts of unoccupied habitat still available for expansion. The slow growth does not appear to be attributable to predation, disease or limiting resources. In North America, Alaska is the only jurisdiction where sea otters are legally hunted (by aboriginal people only under the Marine Mammal Protection Act). Among the reported harvest from 1988 to 2003, 30% were female and this may be a factor even though the reported harvest appears to have been well within the PBR limit of 927 sea otters per year (USFW 2002a; Esslinger and Bodkin 2006).

Potential Sources of human-induced mortality

Sources of human-caused mortality in the B.C. sea otter population are illegal killing, environmental contamination, entanglement in fishing gear, collisions with vessels. Illegal killing does occur and may be of concern. Oil spills are the most significant threat to small sea otter populations. The remaining sources, other environmental contaminants, entanglement in fishing gear, collision with vessels and disease are documented in other sea otter populations and are included here as sources that may be occurring at low levels or may emerge in the future. The following descriptions are taken from the COSEWIC 2006 interim status report.

Oil Spills

Oil is a significant threat to sea otters. In Washington State it is considered the single greatest threat to the viability of that sea otter population (Gerber *et al.* 2004). Oil destroys the water-repellent nature of the pelage which eliminates the air layer, and reduces insulation by 70%. The result is hypothermia and death (Costa and Kooyman 1982; Williams *et al.* 1988). Once fouled, a sea otter grooms itself obsessively and stops feeding, resting and caring for young (Ralls and Siniff 1990). Furthermore as it grooms, the otter ingests oil and inhales toxic fumes which damages internal organs. Methods for cleaning and rehabilitating sea otters exist, but they are costly and the benefits at a population level are questionable (Estes 1991; Williams and Davis 1995).

Several behavioural characteristics predispose sea otters to oil exposure. Sea otters typically rest in sexually-segregated aggregations (rafts) of up to 200 animals, meaning that large numbers of otters can be oiled simultaneously. In addition, rafts of otters often form in or near kelp beds, which accumulate and retain oil (Ralls and Siniff 1990). Finally, otters may be chronically exposed to oil through ingestion of contaminated prey (e.g. mussels) long after the spill has occurred (Bodkin *et al.* 2002).

The effect of contamination from small chronic spills on sea otter populations is not known, but the effect of large spill would be significant. It is generally recognized that the only means to reduce the threat of oil spills to small otter populations is to allow range expansion so that a sufficiently large part of the population will be unaffected (Sea Otter Recovery Strategy 2003; USFW 2003).

On December 23, 1988, the oil barge *Nestucca* was rammed by its tug and spilled 875,000 l of Bunker C oil into the water off Grays Harbor, Washington (Waldichuk 1989). Within 7 days, oil had spread northward to Cape St. James, Queen Charlotte Islands, and was observed throughout the entire British Columbia sea otter range. The spread of oil from this spill, demonstrated the vulnerability of the British Columbia otter population to oil spills although only 1 carcass was retrieved, it is well known that sea otter carcasses on west coast Vancouver Island are quickly scavenged by wolves and eagles (Watson 1990). The *Nestucca* spill, which affected both the Washington State and British Columbia sea otter populations, suggests that in the event of a catastrophic oil spill, it is likely that adjacent otter populations will also be affected

The existing transport of oil along British Columbia's coast poses a threat to the British Columbia sea otter population because of its small size and limited distribution (Watson *et al.* 1997). Risk models for southern British Columbia and Washington State, developed in the 1980s, predicted the following oil spill frequencies: spills of crude oil or bunker fuel exceeding 159,000 litres (1,000 barrels) could be expected every 2.5 years, and spills of any type of petroleum product exceeding 159,000 litres (1,000 barrels) could be expected every 1.3 years (Cohen and Aylesworth 1990). The actual frequency of large spills affecting British Columbia between 1974 and 1991 was fairly close to the predicted frequency (Burger 1992). In addition to large spills, small chronic spills are also of concern. Environment Canada tracks all spills of more than 1,113 litres (7 barrels). There are at least 15 such reportable spills annually along the west coast of Vancouver Island (Burger 1992).

In the spring of 1989, the oil tanker *Exxon Valdez* ran aground in Prince William Sound, Alaska, spilling 42 million litres of crude oil. The impact of this spill on sea otters appears to still persist. At the time, nearly 1,000 sea otter carcasses were recovered, but estimates of total mortality ranged from 2,650 (Garrott *et al.* 1993) to 3,905 animals (DeGange *et al.* 1994). Population modeling showed decreased survival rates in all age-classes in the 9 years following the spill and indicated that the Prince William Sound sea otter population has not yet completely recovered (Monson *et al.* 2000b), As well, elevated levels of cytochrome P4501A, a biomarker for exposure to hydrocarbons, still occur in samples from otters in areas that were heavily oiled, suggesting continued exposure (Bodkin *et al.* 2002). Recovery from EVOS has been slow, this is partially because sea otter recovery in oiled areas has occurred by internal reproduction and some immigration of juveniles but not from widespread redistribution of adults from other parts of Prince William Sound, reflecting the non migratory, small home range characteristics of sea otters (Bodkin *et al.* 2002).

Illegal killing

Illegal killing does occur in British Columbia and is reported to occur in other regions (Rotterman and Simon-Jackson 1988; Bodkin 2003). In other jurisdictions sea otters are shot both legally and illegally for their fur and in an effort reduce their effects on invertebrate stocks. There are no estimates of the magnitude of this source of mortality in British Columbia, but in 2005 and 2006 a total of 5 shot and skinned carcasses of sea otters were reported or recovered on Vancouver Island which suggests that illegal killing may be an emerging threat and the impact may be greater than previously thought (DFO unpubl.).

Environmental contamination - other contaminants

Organochlorine contaminant levels have not been measured in British Columbia sea otters. However, polychlorinated biphenyls (PCB), organochlorine pesticides including DDT, and butyltin have been measured in sea otters from California, Washington and Alaska (Bacon e*t al.* 1999; Kannan *et al.* 2004; Lance *et al.* 2004). PCBs concentrations were higher in Alaskan otters from the Aleutian Islands (309µg/kg wet weight) compared to otters from California (185µg/kg wet weight) and southeast Alaska (8µg/kg wet weight) (Bacon e*t al.* 1999). Total DDT concentrations were highest in California sea otters (850µg/kg wet weight), compared to the Aleutian Islands (40µg/kg wet weight) and southeast Alaska (1µg/kg wet weight). The levels of PCBs measured in California and Aleutian sea otters is considered to be of concern since similar levels caused reproductive failure in mink, a closely related species (Risebrough 1984 *in* Riedman and Estes 1990). Although the levels of DDT measured in California sea otters were not considered to be exceptionally high when compared to other marine mammals (Bacon e*t al.* 1999), reduced immune competence is a well-documented side-effect of contaminants in marine mammals and is considered a possible factor in the high rate of disease-caused mortality in the southern sea otter population (Thomas and Cole 1996; Reeves 2002; Ross 2002). Among a small sample of beach-cast carcasses retrieved for contaminant analysis in California, those that died from infectious disease contained on average higher concentrations of butyltin compounds (components in antifouling paint), and DDTs than animals that had died from trauma and unknown causes (Kannan *et al.* 1998; Nakata *et al.* 1998).

Disease

Sea otter mortality from diseases caused by *Toxoplasma gondii* and *Sarcocystis neurona* is of concern in California (Thomas and Cole 1996; Estes *et al.* 2003), where, 40% of the beach-cast carcasses were of animals that died from disease. In California, from 1968 to 1999 diseases appear to have affected high numbers of prime-age animals, which may be a major factor explaining the low observed rate of population growth (Thomas and Cole 1996; Estes *et al.* 2003). These two pathogens are found in humans and terrestrial mammals whereas sea otters are not considered a normal host. The presence of these pathogens in the marine environment has been linked to domestic sewage and urban and agricultural runoff which transports pathogens into coastal waters where they infect prey species consumed by sea otters (Lafferty and Gerber 2002; Miller *et al.* 2002; Kreuder *et al.* 2003). Both *T. gondii* and *S. neurona* have also been documented in B.C. and Washington State sea otters (Lance *et al.* 2004; Shrubsole *et al.* 2005; Raverty pers. comm. 2006), but the significance of these findings at a population levels is not yet clear.

Entanglement in fishing gear

The extent of accidental drowning of sea otters in fishing gear in British Columbia has not been investigated although there appears to be limited geographic overlap between sea otters and net fisheries at this time except possibly in Queen Charlotte Strait. There is, however, considerable overlap between sea otters and the crab fishery and there are anecdotal reports of otters being drowned in commercial crab pots (J. Watson pers. comm. 2006). Sea otters have become entangled and entrapped in fishing gear in Alaska, California, Washington and Japan (Rotterman and Simon-Jackson 1988; USFW 2003; Lance *et al.* 2004; Hattori *et al.* 2005). As the sea otter range in British Columbia continues to expand, more overlap may be anticipated between sea otters and net and trap fisheries. The increase in shellfish aquaculture may result in some interactions (e.g. entanglement in gear), and this may be a future consideration.

Collisions with vessels

Incidents of collisions with vessels have not been investigated in British Columbia, but are reported from other regions. Vessel strike was the primary cause of death of 5 of 105 beach-cast carcasses examined between 1998 and 2001 in California (Kreuder *et al*. 2003). Vessel strikes are also reported from Alaska (Rotterman and Simon-Jackson 1988). In British Columbia, the occurrence or frequency of vessel strikes has not been investigated, although one incident of probable vessel strike mortality is reported by Watson *et al.* (1997). Although the significance of vessel strikes as a source of mortality is unknown for the British Columbia sea otter population, such incidents may increase has sea otters expand into more areas that are near human habitation.

Aggregate total human-induced mortality

It is not possible to quantify total human induced mortality at this time. Reported illegal kills represent an unknown portion of total illegal kill and thus only provides substantiating evidence that the activity occurs. Oil spills remain the biggest threat to small populations of sea otters.

RECOMMENDATIONS

1. If a directed take is considered, it should be deferred on the central B.C. coast primarily because the number of sea otters there is far below an effective population size that has been established as a critical level for southern sea otters and a threshold that may well be relevant for the sea otter population in B.C..

2. A simple logistic model predicts a level of human caused mortality on the west coast of Vancouver Island that would delay recovery by 10%. However, the predictions are based on estimates of habitat carrying capacity, growth rate and on the assumption that current levels of mortality will remain constant. Yet the variance of population surveys (*CV* 0.07 - 0.12) indicates that trends including declines, unless precipitous would be difficult to detect. For these reasons the lower level of allowable harm 40 sea otters per year is recommended as a precautionary measure if a directed take is considered.

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Table 1. Summary of recent population estimates, status and habitat derived carrying capacity estimates among sea otter populations in North America.

Region	Population Size	Year of Population Estimate	Status*	Carrying Capacity Estimate	Source
California	2,735	2005	Threatened (ESA)	15,941 (95% *CI* 13,538 – 18,577)	Laidre *et al.* 2001; USGS 2005
Washington	814	2004	Not listed (ESA)	1,372 (*CV* 0.13) to 2,734 (*CV* 0.13)	Laidre *et al.* 2002; Jameson and Jeffries 2004
British Columbia	3,200	2001- 2004	Threatened (SARA)	14,884 (95% *CI* 9,798 - 20,769) *to* 52,199 (95% *CI* 48,672 - 59,018)	Nichol *et al.* 2005; Gregr *et al.* (in Press)
Southeast Alaska	12,600	1994-1996	Not listed (ESA)		USFW 2002a
Central Alaska	16,552	1996, 1999, 2002	Not listed (ESA)		USFW 2002b
Western Alaska	41,500	2000-2002	Threatened (ESA)		USFW 2002c
Aleutian Islands	8,742 (*CV* 0.215)	2000		105,391 (95% *CI* 73,589 – 146,607)	USFW 2002c; Burn *et al.* 2003

Table 2. Habitat area, otter density, and carrying capacity estimates from 3 model approaches for two regions of the B.C. coast, west coast Vancouver Island and Fisheries Statistical Areas 6 and 7 on the central B.C. coast. This table is adapted from Gregr *et al.* (in Press).

	Model (density)											
	WCVI Optimum (3.93 otters/km^2)				BC Optimum (2.53 otters/km^2)				Linear (2.22 otters/km)			
Region	Habitat (km^2)	*K* (otters)	CI (2.56 – 5.45)		Habitat (km^2)	*K* (otters)	CI (1.67 – 3.54)		Habitat (km)	*K* (otters)	CI (1.45 – 3.11)	
WCVI	1,304	**5,123**	3,337	7,104	1,931	**4,887**	3,226	6,837	3,740	**8,303**	5,424	11,633
Stat 6,7					1,032	**2,687**	1,723	3,652	8,994	**20,506**	13,041	27,971

Table 3. West Coast Vancouver Island, years to reach recovery target 0.80K in the absence of additional mortality (C = 0). R_{max} = 0.18. From survey counts, minimum population size in 2004 was 2,765 sea otters.

Model Scenario #	Model Parameters	Predicted population size in 2004	Yrs. to $0.80K$ [#]	Yr. of recovery
1	K = 5,000, θ = 1	2,934	33	2010

[#] 1977 = year 0,
80% of K is 4,000.

Table 4. Central B.C. Coast, (Statistical Areas 6 and 7), details of model scenarios and years to reach recovery target 0.80K in the absence of additional mortality (C=0). R_{max} = 0.18. From survey counts, minimum population size in 2004 was 420 sea otters.

Model Scenario #	Model Parameters	Predicted population size in 2004	Yrs. to $0.80K$ [#]	Yr. of Recovery
1	K = 2,700, θ = 1	489	31	2021
2	K = 3,700, θ = 1	508	33	2023

[#] 1990 = year 0
80% of K is 2,160 and 2,960 respectively.

Table 5. Vancouver Island, estimates of allowable annual mortality commencing in 2007 (year 30) according to two recovery target outcomes. A: annual mortality that does not delay YTR by more than 10%. B: An annual mortality that does not delay YTR by more than 10% and that also allows the population to continue to grow to 0.95K .

Model Scenario #	Model Parameters	A	B
1	K = 5,000, θ = 1	90	40

Table 6. Central coast (Statistical Areas 6 and 7), estimates of allowable annual mortality commencing in 2007 (year 17) according to two recovery target outcomes. A: an annual mortality that does not delay YTR by more than 10%. B: An annual mortality that does not delay YTR by more than 10% and that also allows the population to continue to grow to 0.95K.

Model Scenario #	Model Parameters	A	B
1	K = 2,700, θ = 1	20	20
2	K = 3,700, θ = 1	25	25

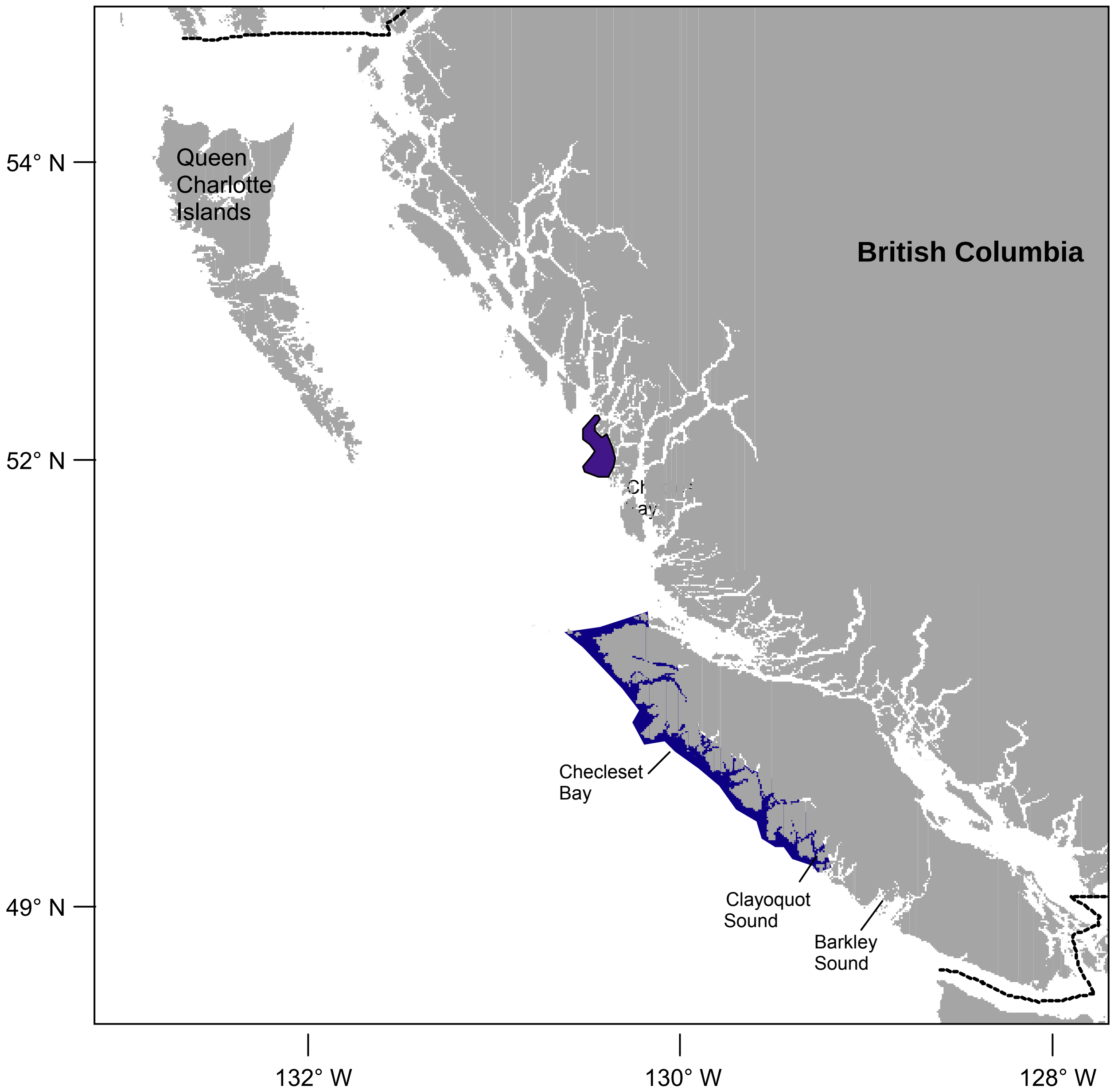

Figure 1. The range of the sea otter in Canada as of 2004 (shaded areas). Canada-U.S. borders (dashed line).

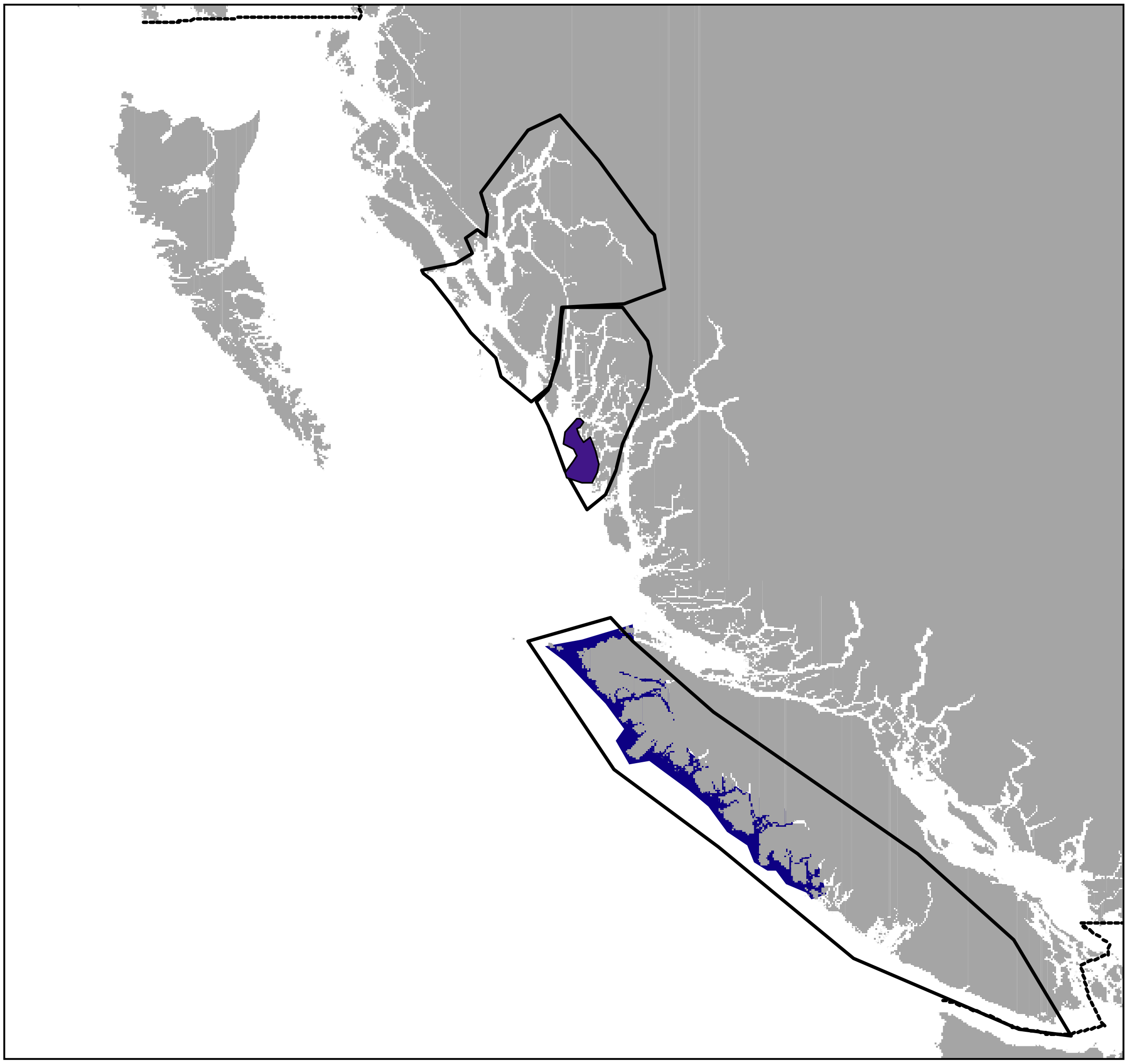

Figure 2. The range of the sea otter range in Canada (shaded areas). Geographic regions on west coast Vancouver Island and central B.C. coast over which carrying capacity was estimated (polygons) for allowable harm assessment. Canada-U.S. borders (dashed line).

APPENDIX 1: All results from models for west coast Vancouver Island and central B.C. coast

West coast Vancouver Island

R_{MAX} is 18% and Initial population size in 1977 (year 0) = 70.

Shape = 1, K = 5000, Population size in 2007 (year 30) = 3560.

Human induced mortality (per year)	Years to target population
	Target .8K
0	33
10	33
20	33
30	34
40	34
50	34
60	35
70	35
80	36
90	**36**
100	37
120	40
140	54
160	>1000
180	decline
200	decline
220	decline

Bold = Outcome A
Gray = Outcome B

Central B.C. coast (Statistical Areas 6 and 7):

R_{MAX} is 18% and initial population size in 1990 (year 0) = 56.

Shape = 1, K = 3,700, Population size in 2007 (year 17) = 775

Human induced mortality (per year)	Years to target population
	Target .8K
0	33
10	34
20*	**35**
30	37
40	39
50	41
60	44
70	48
80	53
90	61
100	77
120	decline
140	decline
160	decline
180	decline
200	decline
220	decline

Bold = Outcome A and B

* allowable take in this scenario is 25 with years to target = 36

Shape = 1, K = 2,700, Population size in 2007 (year 17) = 728.

Human induced mortality (per year)	Years to target population
	Target .8K
0	31
10	32
20	**34**
30	36
40	39
50	43
60	48
70	59
80	>1000
90	>1000
100	decline
120	decline
140	decline
160	decline
180	decline
200	decline
220	decline

Bold = Outcome A and B