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Recovery Potential Assessment of western North Atlantic right whale (*Eubalaena glacialis*) in Canadian waters

Évaluation du potentiel de rétablissement de la baleine noire (population de l'ouest de l'Atlantique Nord (*Eubalaena glacialis*) dans les eaux canadiennes

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ABSTRACT

The Western North Atlantic right whale is listed as Endangered under the Species at Risk Act. This document presented analyses that were undertaken in support of the Recovery Potential Assessment of western North Atlantic right whale held in 2007. This evaluation will inform recovery planning for right whale in Canadian waters.

Population abundance is critically low, numbering approximately 325-350 individuals through 2003. The best available population model indicates a declining trend in abundance over the period of 1980-1995. If the 1995 growth rate was maintained, the population model predicts an average time to extinction of about 200 years. Critical Habitat was defined as including concentrations of right whale prey, especially stage C5 Calanus finmarchicus copepodites, and the environmental, oceanographic and bathymetric conditions that aggregate right whale prey at interannually predictable locations. An interim, science-based recovery target for right whale population abundance was provided: "An increasing trend in abundance over three generations". Generation time for right whale is approximately 20 years; therefore the minimum time period necessary to achieve this target is around 60 years. It was determined that scope for allowable human-induced mortality does not exist currently, since population abundance was estimated as critically low and the population appears to be declining toward extinction. The two major known threats to right whale survival are vessel strike and entanglement in fishing gear. These to threats account for all known human-induced mortality. Other potential threats have been identified, but their effect on right whales is uncertain.

RÉSUMÉ

La baleine noire (population de l'ouest de l'Atlantique Nord) est désignée en tant qu'espèce en voie de disparition en vertu de la Loi sur les espèces en péril. Le présent document présente les analyses qui ont été entreprises pour soutenir l'évaluation du potentiel de rétablissement de la baleine noire (population de l'Atlantique Nord) qui a eu lieu en 2007. Cette information sera utilisée dans le processus de planification du rétablissement de la baleine noire dans les eaux canadiennes.

L'abondance de la population est dangereusement faible, puisqu'elle totalisait entre 325 et 350 baleines en 2003. Le meilleur modèle de la population disponible montre une tendance à la baisse entre 1980 et 1995. Si l'on suppose le maintien du taux de croissance de l'année 1995, la prévision selon le modèle de population serait la disparition de la population d'ici environ 200 ans. L'habitat essentiel comprend les zones de concentration des proies de la baleine noire, surtout les jeunes stades copépodites C5 de Calanus finmarchicus, et affiche des conditions environnementales, océanographiques et bathymétriques qui favorisent la concentration des proies de la baleine noire à des endroits prévisibles, année après année. L'objectif de rétablissement provisoire fondé sur des données scientifiques pour la population de baleine noire est le suivant : « Maintenir une tendance à la hausse pendant trois générations ». La durée d'une génération chez la baleine noire est d'environ 20 ans; par conséquent, la période minimale nécessaire pour atteindre l'objectif est de 60 ans approximativement. On a déterminé qu'aucun taux de mortalité d'origine anthropique admissible ne pouvait s'appliquer présentement, car l'abondance de la population est considérée comme dangereusement faible et la population semble sur la voie de l'extinction. Les deux principales menaces pesant sur la survie de la baleine noire sont les collisions avec les navires et l'enchevêtrement dans les engins de pêche. Ces menaces comptent pour tous les cas de mortalité anthropique connus. D'autres menaces potentielles ont été relevées, mais leur effet sur les baleines noires demeure incertain.

Introduction

The Species at Risk Act (SARA) provides legal protection to species listed in Schedule 1 including the western North Atlantic right whale. Under SARA it is prohibited to kill, harm, harass, capture or take an individual of this population and also to destroy any part of its critical habitat. Section 73 of SARA authorizes competent Ministers to permit otherwise prohibited activities affecting a listed wildlife species, any part of its critical habitat, or the residences of its individuals if certain preconditions are met. Examples of such activities include research in support of recovery efforts, eco-tourism (whale-watching), and by-catch in commercial fisheries. A recovery strategy, and subsequently an action plan, is required for all wildlife species listed in Schedule 1 as threatened, endangered, or extirpated.

Decisions made on permitting of harm and in support of recovery planning need to be informed by the impact of human activities on the species, alternatives and mitigation measures to these activities, and the potential for recovery. An evaluation framework, consisting of three phases (species status, scope for human–induced harm, and mitigation) has been established by DFO to allow determination of whether or not SARA incidental harm permits can be issued. The analysis provided herein will inform issuance of incidental harm permits and recovery planning for the Western North Atlantic right whale. In the context of this status report, “harm” refers to all prohibitions as defined in SARA.

Background

The North Atlantic right whale was the first whale species to be commercially exploited, and it played a large role in the development of the whaling industry. Whaling for right whales in the western Atlantic may have been undertaken by Basque whalers during the 16^{th} and 17^{th} centuries during their hunt for bowhead whales in the Strait of Belle Isle. In the US, the same population was the target of coastal whaling during 18th, 19th and early 20th centuries. As a consequence, the population was reduced to very low levels by the beginning of the 1900s. Harvest of right whales has been banned internationally since 1935.

The western North Atlantic right whale (*Eubalaena glacialis*) is a large baleen whale (up to 16 metres, females a metre longer, adults weigh about 70 tonnes), generally black in colour with occasional white belly patches and no dorsal fin.

Calving grounds are located in the southern (Florida, Georgia), winter portion of the range, and almost all of the sightings at this time and area are of females and their calves. Where males and non-pregnant females overwinter is unknown. Late winter and spring feeding aggregations of right whales are observed in Cape Cod Bay Massachusetts Bay and the Great South Channel. In Canadian waters, concentrations of foraging right whales are seen in the Bay of Fundy and Roseway

Basin (southwestern Scotian Shelf) during the summer and autumn. Much smaller numbers of whales are seen in other areas, such as the Gaspé region of the Gulf of St. Lawrence; however sighting effort is much lower in these areas. By late autumn, most right whales begin to disperse to wintering areas, although there have been sightings of right whales in the Bay of Fundy as late as December, and right whale vocalizations have been detected on Roseway Basin as late as December.

Data on longevity are not available, but the oldest individual on record is estimated to have been 70 years old when last seen. Females are seen with their first calf at approximately nine years of age. Age at maturity for male right whales has not been determined. The sex ratio is approximately 50/50.

Right whales give birth to a single calf. The mean interval between births was 3.7 years with a range of 2-7 years. In the 1990s, the mean calving interval increased significantly to nearly 6 years, and recently returned to levels observed previously. It has been estimated that 26% to 31% of the population are juveniles (< 9 years of age), significantly lower than the level observed in some other baleen whales.

North Atlantic right whales require a concentrated source of zooplankton (usually copepods) with relatively high energy content in order to meet feeding requirements. In Canadian waters, right whales are thought to feed primarily on the calanoid copepod, *Calanus finmarchicus*, especially on the diapause copepodite C5 stage. This species is the most abundant copepod on the Scotian Shelf and in the Bay of Fundy. The C5 stage exhibits relatively large energy stores in the form of high-energy lipids.

PHASE 1: Assess Current Species Status

Present species status for abundance and range

Abundance

The population of right whales (*Eubalaena glacialis*) in the western North Atlantic was estimated in the COSEWIC Status Report (COSEWIC 2003) to number about 322 animals. The COSEWIC report did not present the methods used to estimate population size, however the estimate represents the number of individually identified (by photo ID) right whales thought to be alive in 2003. The US National Marine Fisheries Service (NMFS) provides a population estimate of between 300-350 individuals (NMFS 2005). Kraus et al. (2005) suggest that there are no reliable estimates of right whale population abundance beyond stating that about 300 animals remain. Hamilton et al. (1998) estimated that 60% of the females are adults, which given a 50/50 sex ratio, results in an estimate of approximately 90-105 adult females in recent years. In addition, 26% to 31% of the population is composed of calves and juveniles (Hamilton et al. 1998). This results in about 222-238 mature individuals, as of several years ago.

Range

Right whales currently seasonally occupy nearly the full extent of what is considered to be their historical range (Figure 1), although most research efforts are concentrated on the areas between Florida and Bay of Fundy/western Scotian Shelf. Right whales have not been sighted for more than a century in what are considered to be historical whaling grounds in the Strait of Belle Isle between Labrador and Newfoundland. Here the population's range is believed to have overlapped that of the bowhead whale (Aguilar 1986; Cumbaa 1986). Note that two Right Whale Conservation Areas were identified in 1993 in Canadian waters; one in the lower Bay of Fundy, east of Grand Manan Island, and the other in Roseway Basin, on the southwestern Scotian Shelf (Figure 1).

Recent species trajectory for abundance and range

Abundance trends

The population appears to have declined over the period of 1980-1995 (Caswell et al. 1999; Fujiwara and Caswell 2001; Caswell and Fujiwara 2004). Fujiwara and Caswell (2001) used photo-identification data as input into a multiple mark-recapture framework, and developed a stage-based, matrix projection model of the population. The authors calculated the asymptotic population growth rates (λ) for the period of 1980 to 1995 and concluded that the growth rate declined from 1.03 (SE=0.02) in 1980 to 0.98 (SE=0.03) in 1995. If the 1995 growth rate was maintained, population projection simulations predict a mean time to extinction of about 200 years. Several right whale population models have been published, but the Fujiwara and Caswell (2001) model is considered to produce the most accurate estimates of trends in population vital rates (Kraus et al. 2005).

Based on analyses of stranding, entanglement, and photographic data, Kraus (1990) and Kenney and Kraus (1993) estimated that mortality ranged between 5% and 18% during the first three years of life. Adult mortality rates are very low, probably less than 1% annually, although Fujiwara and Caswell (2001) suggest that adult female mortality rates are substantially higher, which of great conservation concern. This declining trend in survivor of breeding females has driven the decline in population growth rate to levels below replacement (Fujiwara and Caswell 2001; Kraus 2002).

Low reproductive rates and declining survival probabilities have prevented recovery in this population over the last 25 years (Kraus et al. 2005). Most known right whale mortalities are due to human activities; namely vessel strike and entanglement in fishing gear. However, Fujiwara and Caswell (2001) demonstrated that if the 1995 value of λ is used (0.98) and annual mortalities of breeding females are reduced by just two individuals, λ becomes positive and the population would thus increase in abundance. Additionally, the average (time-invariant) value of λ over the time series is positive (λ=1.025; Caswell and Fujiwara 2004). Note, however, that λ is a **rate**, and the above calculation of Fujiwara and Caswell (2001) is based on a starting abundance of 150 adult females. As abundance increases more mortalities will have to be prevented, since the number of deaths that result in a given mortality rate will also increase. The key to increasing survivor appears to be mitigation of human impacts on the population; if human-induced mortalities can be sufficiently reduced, the population appears to have the capacity to recover.

Trends in range occupancy

There has been no apparent shift in occupancy of the historical range during recent years (10-20 years). However, there have been seasonal shifts in distribution of right whales on feeding grounds in the Great South Channel in 1992 (Kenney 2001), on Roseway Basin and in the Bay of Fundy (1993-1998), probably in response to shifts in the abundance and distribution of their prey.

Characteristics of Critical Habitat and Amount of Critical Habitat currently available

In this section existing research concerning habitat requirements of the North Atlantic right whale in Canadian waters is reviewed in order to construct a description of generic Critical Habitat, and to identify areas that match this description. The consequences of designating areas as Critical Habitat are not evaluated, nor are specific management measures proposed. The evaluations presented in this document do not represent a final determination of Critical Habitat for North Atlantic right whale.

Description of right whale habitat in Canadian waters

The North Atlantic right whale undertakes a seasonal migration each year. The only known calving grounds are located in the southernmost portion of the range. Mothers, newborn calves and some juveniles generally spend the winter months (December to March) in the south off the coast of Florida and Georgia. Some right whales are seen in Cape Cod Bay in the winter and more recently there have been some sightings in the Gulf of Maine; however, exactly where males, non-pregnant females and juveniles may overwinter is largely unknown. Some right whales, primarily juveniles, are known to transit back and forth between Cape Cod Bay and the waters off of Florida in Georgia in the winter months. Later in winter and early spring, right whales generally move northward along the US east coast and at this time aggregations in Cape Cod Bay are observed (Figure 1). As the spring progresses, whales continue northward and during late spring - early summer they can be found in Massachusetts Bay and the Great South Channel (Figure 1). Concentrations of right whales are seen in the Bay of Fundy and Roseway Basin (southwestern Scotian Shelf) during the summer and autumn. Much smaller numbers of whales are seen in the Gaspé region of the Gulf of St. Lawrence and coastal Newfoundland during this time; however sighting effort is much lower in these areas. By late autumn, right whales begin to head southward. The summer and autumn residency areas of approximately one-third of the population are unknown currently.

Feeding habitat

The prevailing theory is that right whales enter Canadian waters to feed and socialize. Although some feeding is observed by the few whales found in the winter months in Cape Cod Bay, mothers are thought to fast during the southern portion of their annual migration. It is therefore likely that successful feeding in the northern part of their range is essential for the development of substantial energy reserves.

Specific areas within Canadian waters are considered to provide feeding habitat. All births occur in US waters. The Bay of Fundy is the only known “nursery” area in Canadian waters. Two-thirds of right whale mothers bring calves to the Bay, and these mothers exhibit philopatry to this nursery habitat (Malik et al. 1999). As of the early 1990s, up to 66% of all females with calves had been sighted in the Bay of Fundy (Schaeff et al. 1993) and through 2004 over 95% of the population identified in the photo ID catalogue.

In the Bay of Fundy and along the Scotian Shelf, right whales are thought to feed almost exclusively on the calanoid copepod, *Calanus finmarchicus*, especially on the diapause copepodite C5 stage. This species is the most abundant copepod on the Scotian Shelf (Herman et al. 1991) and dominates the prey field in the Grand Manan Basin area (e.g. Murison and Gaskin 1989; Woodley and Gaskin 1996; Michaud 2005). The C5 stage exhibits relatively large energy stores in the form of high-energy lipids (Michaud 2005), which is likely why right whales may target aggregations of C5 copepodites.

Right whales may only feed when concentrations of prey reach a threshold density. For example, surface feeding was only observed when zooplankton concentrations exceeded 10^3 m^{-3} in Cape Cod Bay (Mayo and Marx 1990) and 10^4 m^{-3} in the Great South Channel (Wishner et al. 1988). Kenney et al. (2001) proposed that right whale foraging is more efficient if prey are aggregated rather than dispersed as this leads to increased net energy gain per unit of foraging effort.

Grand Manan Basin, Bay of Fundy

Much of the research studying the biophysical characteristics of right whale habitat has been undertaken in the Bay of Fundy. The use of the Grand Manan Basin by right whales will be summarized below, and will serve as the main description of what is known about habitat requirements in Canadian waters. Additional areas of aggregation exist in Canadian waters; however biophysical characteristics of these areas are not well described because of a lack of oceanographic sampling coincident with the presence of right whales. Also, opportunistic sightings data suggest that additional habitat areas in Canadian waters likely exist, but the importance of these areas is unknown because of lack of effort.

The lower Bay of Fundy, and particularly Grand Manan Basin, is occupied by right whales for up to seven months of the year (June - December), with the largest aggregations of whales seen in August and September. The edges of the Basin lie at about 100 m depth, and the maximum depth of the central Basin is approximately 200 m. The area is exposed to strong tides, with amplitudes up to 5 m and velocities greater than 1.5 ms^{-1} (Greenberg 1983). The topography, prevailing currents, and oceanic fronts present in Grand Manan Basin may concentrate the copepod population (Wishner et al. 1995; Michaud 2005).

The highest concentrations of copepods in the Bay of Fundy are located in Grand Manan Basin (Murison and Gaskin 1989; Woodley and Gaskin 1996; Baumgartner and Mate 2003). Michaud (2005) demonstrated that the concentration of stage C5 *C. finmarchicus* in the Basin was relatively high during the period of August to October. Energy content of these C5 was greatest during September and October, the same period of peak right whale sightings in the Bay of Fundy. Murison and Gaskin (1989) reported that right whales were sighted in areas of relatively high copepod biomass (depth integrated), and that assumed foraging dives were only observed where copepod densities exceeded $10^3 m^{-3}$. Baumgartner and Mate (2003) used depth-recording tags to determine that right whales were feeding at depths of 100-150 m in the Basin. The concentrations of *C. finmarchicus* at these depths and in areas associated with feeding dives always exceeded $3x10^3$ m^{-3}, with a maximum concentration in this deep layer of $2x10^4$ m^{-3} (Baumgartner and Mate 2003; Baumgartner et al. 2003b).

The peak concentration of C5 *C. finmarchicu*s in Grand Manan Basin is found at shallower depths than in other areas of the Scotian Shelf that exhibit relatively high concentrations of copepods at depths often greater than 200 m (Sameoto and Herman 1990; Miller et al. 1991). Baumgartner et al. (2003a) hypothesized that this shallower availability would result in lower energy demand for foraging compared to areas where the peak concentration is located at greater depths. This reduced energy cost may explain why right whales are not sighted frequently in other, relatively deep basins on the Scotian Shelf that contain high concentrations of C5 *Calanus*. The exception is Roseway Basin, which at approximately 150 m is not as deep as some of the other shelf basins.

Energy Requirements
North Atlantic right whales require a concentrated source of zooplankton (usually copepods) with relatively high energy content in order to meet feeding requirements. As stated earlier, right whales feed primarily on *Calanus finmarchicus*.

Michaud (2005) estimated that within Grand Manan Basin the tidal currents and bottom topography produce an area wherein the prey field availability and its total energy content are sufficient to meet the basal metabolic requirement of right whales. Michaud (2005) observed that the peak layer of energy density (approximately 10 m thick and greater than 10 kJm^{-3}) within the Basin was spatially patchy but widely distributed. In addition, she observed patches with energy density in excess of 30 kJm^{-3}, which corresponds to four times the basal daily requirement of right whales. Given the observed energy density of >10 kJm^{-3} and an assumed foraging swimming speed of 1.2 ms^{-1}, it would take from 2-22 hours for a right whale to meet its basal requirements, with a median time of 9 hours (Michaud 2005).

Energy Availability/Grand Manan Basin Carrying Capacity
Michaud (2005) used prey abundance and energy content to develop a rough approximation of the energy available to right whales in the Grand Manan Basin. She then used simple energetic models to estimate right whale energy demand. Using these two estimates, Michaud (2005) derived an approximation of the carrying capacity of the feeding habitat in Grand Manan Basin, using a range of assume foraging times, whale abundance, and food-energy density, and the assumption that right whales do not feed during the rest of the year. In summary, the average energy available varied from 8 to 94 kJm^{-3}. This variation translates to a range in the minimum time required to meet daily demand of 2 to 26 hours. To estimate carrying capacity, Michaud (2005) assumed a residency period of 5 months for 200 individuals weighing 40 tonnes each; this represents the usual period of observed occupancy and approximately two thirds of the population, respectively. Using this model, Michaud (2005) concluded that in 2002, the prey field in Grand Manan Basin could just meet the annual energy requirements of 200 whales. The general conclusion from this work is use of the Bay of Fundy habitat by right whales MAY be near or at carrying capacity. It is likely that the availability of additional habitat will be necessary to support substantial population growth. For example it is know that right whales transit between the Bay of Fundy and a second feeding area on Roseway Basin during August and September (Stone et al 1986 and New England Aquarium unpublished data).

There are several assumptions in the calculations reported by Michaud (2005) that may influence the estimate of “just” meeting the requirements of 200 whales.

(a) No input of food energy during season. This is a reasonable assumption, based on present knowledge of local prevailing currents.
(b) No other sources of C5 loss. This assumption likely results in an overestimate of energy available to right whales, as there are other known

predators in the area (copepods are the basis of the food chain e.g. herring, basking shark, sei whale).

(c) Abundance. Two hundred whales is near the maximum likely to be present (126 individual whales were identified in the Bay of Fundy during 2002; New England Aquarium, pers. comm.)

(d) Feeding is the only additional cost. This assumption underestimates energy requirements, as the cost of social interaction (Surface Active Groups), reproduction, and lactation are ignored.

Definition of generic Critical Habitat

Critical Habitat for right whale in Canadian waters must allow successful feeding to ensure that sufficient energy reserves are accumulated to support the energetic cost of basal metabolism, growth, reproduction, and lactation. Critical Habitat has to provide this level of foraging success for right whales on a predictable, interannual basis. Given what is known about prey preference of right whales and the distribution of their prey, a fairly robust, science-based description of generic Critical Habitat for right whale can be proposed: Critical Habitat includes concentrations of right whale prey, especially stage C5 *Calanus finmarchicus* copepodites, and the environmental, oceanographic and bathymetric conditions that aggregate right whale prey at interannually predictable locations.

Why should areas that allow predictable feeding success be considered for Critical Habitat designation? It has been hypothesized in several studies that variation in right whale condition, reproductive rate, and spatiotemporal distribution may be related to successful foraging (Caswell et al. 1999; Kenney et al. 1995; 2001). For example, during the 1990s the calving interval increased from 3 to 6 years (Kraus et al. 2001), and during the same period whales that had usually been sighted in Roseway Basin were seen in the Bay of Fundy (Kenney 2001). The working hypothesis among right whale researchers is that during this period copepod concentration in Roseway Basin was insufficient to meet right whale energy demands, and thus right whales moved into another predictable habitat nearby – Grand Manan Basin. The Basin may have lacked the energy reserves necessary to support the increased number of whales in the Bay, and thus may have played a role in the observed reproductive failure (increased calving interval). This period of extended calving intervals was followed subsequently by 5 years of relatively high birth rates in years (Kraus et al. 2005), during which right whales were observed again in Roseway Basin.

Candidate areas of Critical Habitat

An obvious candidate for Critical Habitat is the Grand Manan Basin, in the lower Bay of Fundy. There already exists a Right Whale Conservation Area in the Basin (designated in 1993), which could reassessed for use of specific coordinates.

Every year the Basin area is frequented by a substantial number of the right whales, and in some years up to two thirds of the known extant population have been sighted in this region. Much of the research concerning right whale habitat (and all of the research that has occurred in Canadian waters) has been undertaken in and around Grand Manan Basin.

A second candidate for Critical Habitat designation is Roseway Basin Conservation Area, on the Southwestern Scotia Shelf. This is a known area of aggregation of right whales, and the area has been the focus of substantial research, but not to the same degree as the Bay of Fundy. A proposal shortly will be presented to the International Maritime Organization to have the area declared an Area To Be Avoided by vesselping. A research project has been designed to evaluate this area.

Population and Distribution targets for Recovery

Using whaling records and a 50/50 sex ratio, Gaskin (1991) estimated pre-exploitation abundance to be in the range of 12 000 to 15 000 whales. Taking this estimate at face value, estimates of current population abundance are approximately 2-2.9% of historical abundance. However, this pre-exploitation abundance estimate has been questioned by recent work in population genetics. Malik et al. (1999) found only five matrilines represented in the mitochondrial DNA from over 200 animals sampled in the western North Atlantic population, suggesting that the population went through a very small "bottleneck" at some time in the recent past. In addition, Waldick et al. (2002) determined that the genetic bottleneck did not occur during the most recent decline attributable to whaling; during the 18th-20th centuries. This suggested that earlier whaling by the Basques during the 16th and 17th centuries may have been responsible for the abundance decline. Basque whaling in the Gulf of St. Lawrence area was thought to target both right and bowhead whales (Aguilar 1986; Cumbaa 1986). However, Rastogi et al. (2004) performed a genetic analysis on 21 bones recovered from a Basque whaling site at Red Bay, NF, and found that only one bone originated from a right whale. The rest of the bones were identified as originating from bowhead whales. To date, this analysis has been expanded to bones from over 50 individuals, and no additional right whale bones have been identified. Together, these genetic analyses support an alterative hypothesis that the reduction in genetic variability and population abundance predates whaling. Pre-exploitation population abundance may have been an order of magnitude lower than the estimate provided by Gaskin (1991).

A provisional, science-based Recovery Target for the Western North Atlantic Right Whale is:

> "*To achieve a positive trend in population abundance over three generations"*

Three right whale generations corresponds to approximately 60 years (e.g. COSEWIC 2003). This recovery goal has yet to be approved by DFO. The current abundance is dangerously low and the best estimate of population growth rate is negative (see above). There is an immediate requirement to reduce the probability of extinction through fostering positive population growth rates and increasing abundance. It is difficult to provide firm recovery targets for right whales because a clear threshold for abundance that would ensure their long-term survival is not known. Nevertheless, it is important to state a desirable (positive) trend in population growth in order to provide a context for the development and implementation of recovery measures and research activities.

General time frame for recovery to target

It is possible to evaluate rough estimates of future population trends using long term projections of existing, published models. The task in this item of the RPA is to estimate a general time frame for recovery under the assumption that the population is only exposed to natural mortality (human-induced mortality is set to zero). For this task a matrix population projection model was constructed following the formulation of Fujiwara and Caswell (2001). Parameters for the stage transition matrix are drawn directly from Caswell and Fujiwara (2004). These values in the projection matrix represent the mean (time-invariant) vital rates generated from mark-recapture data for the period of 1980-1995. The simulation models female stages only.

Estimates of total mortality in North Atlantic right whale exist, but unfortunately concomitant estimates natural mortality do not. For example, Knowlton et al. (1994) estimated total mortality in North Atlantic right whales as 0.021 ± 0.003. This estimate is likely an overestimate, as it does not exclude anthropogenic mortality, and Knowlton et al. (1994) concluded that total mortality may be twice as high as natural mortality. It is thus necessary to turn to closely related species for proxy values of natural mortality. Best and Kishino (1998) reported estimates of natural mortality in reproductively active females in a population southern right whales, *Eubalaena australis*, located off South Africa. The congeneric southern right whale is considered to be related sufficiently closely to North Atlantic right whales for comparison of life history components. Using two different methods, Best and Kishino (1998) estimated natural mortality as 0.0255 ± 0.0071 or 0.0227 ± 0.0192. Best and Kishino (1998) state that right whales appear to have adult natural mortality rates of 1-3%, and stated that most estimates suggest a value near 2%.

Following the conclusions of Best and Kishino (1998), the population simulation model presented in this paper sets natural mortality in the adult stages at 0.02 (the mid-range of 1-3%), and allowed this value to vary randomly (uniform distribution) between 0.01 and 0.03. This natural mortality and variation is applied to each of the adult female stages in the projection matrix. Note that the model actually incorporates survivor (1-natural mortality), rather than mortality. Survivor rates were varied at each time step (1 year). Model runs were 30 years in duration, with at total of 50 runs undertaken during the simulation. Estimates of right whale abundance at stage for the year 2004 (New England Aquarium, pers. comm.) were used to initialize the population model. Results are presented in Figures 2 and 3.

In summary, under the condition of only natural mortality, the population projection model of Fujiwara and Caswell (2001) predicted population growth at the rate of about 6% per year. This is not surprising, as growth rates for the southern right whale population found off South Africa have been estimated at approximately 7% per year (Best 1990), and natural mortality levels used in the simulation above are derived from studies on this South African population. The simulation model predicts the timeframe for recovery in abundance (in the absence of human-induced mortality) requires at least order decades. The doubling time from the initial population abundance is approximately 12 years.

Residence requirements

Section 2(1) of SARA defines a residence as a “dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating”. Western North Atlantic right whales do not occupy residences as residences are defined under the Act.

PHASE II: Scope for Human-Induced Mortality

Maximum sustainable human-induced mortality

Kraus et al. (2005) report that low reproductive rates and declining survival probabilities have prevented recovery over the last 25 years, and suggest that there are no reliable estimates of right whale population abundance beyond stating that about 300 animals remain. Further, the population appears to have been declining over the period of 1980-1995 (Caswell et al. 1999; Fujiwara and Caswell 2001; Caswell and Fujiwara 2004). Fujiwara and Caswell (2001) used population projection simulations predict a mean time to extinction of about 200 years, based on data up to 1995. Hamilton et al. (1998) estimated and extant adult female population of approximately 90-105 individuals in recent years. The evidence from these studies strongly suggests the existence of an extremely small breeding population that is currently following a trajectory toward extinction. Breeding populations this low in abundance may also face detrimental effects from demographic stochasticity (e.g. Lande 1993).

It is highly unlikely that any scope for allowable mortality exists for the near term, given:

a) the population abundance is critically low;
b) models suggest the population is on an extinction trajectory ($\lambda<0$); and
c) the mortality rate of a key life stage (adult females) appears to have increased during recent years.

The population has to stabilize (cease declining) first. What levels of non-lethal harm may be permissible is not apparent and nearly impossible to evaluate with confidence. Any level of non-lethal harm that may impede population productivity would put recovery at risk, given the population's trajectory toward extinction. Note that in US waters, under the Marine Mammal Protection Act the Potential Biological Removal* (PBR) for right whales has been set to zero (Waring et al. 2005). PBR=0 is functionally equivalent to prohibiting mortality due to human activities.

The need for zero human-induced mortality may be revisited in the future if the population rebounds from critically low abundance. Fujiwara and Caswell (2001) demonstrated that if the 1995 value of the asymptotic population growth rate (λ) is used (0.98) and annual mortalities of breeding females are reduced by just two individuals, λ becomes positive and the population would thus increase in abundance. Additionally, the average (time-invariant) value of λ over the time series is positive ($\lambda=1.025$; Caswell and Fujiwara 2004). This implies that the population may be able to sustain a small amount of human-induced mortality. Note, however, that λ is a **rate**, and the above calculation of Fujiwara and Caswell (2001) is based on a starting abundance of 150 adult females. As abundance increases more mortalities will have to be prevented, since the number of deaths that result in a given mortality rate will also increase. The key to increasing survivor appears to be mitigation of human impacts on the population; if human-induced mortalities can be sufficiently reduced, the population appears to have the capacity to recover.

Major potential sources of harm

Collision with vessels (vessel strike)

Mortality from vessel strikes is a serious, known threat to the survival of western North Atlantic right whale. Vessel collisions have been recognized as an important cause of mortality for decades (Reeves et al. 1978; Kraus 1990).

*Potential Biological Removal (PBR) level is defined under the MMPA as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing the stock to reach or maintain its optimum sustainable population. The potential biological removal level is the product of a) the minimum population level of the stock; b) one-half the theoretical or estimated net productivity rate of the stock at a small population size; and c) a recovery factor between 0.1 and 1.0.

collisions or gear entanglement. Half of human-induced mortalities were due to vessel strikes. In addition direct (proximal) mortality, about 7% of the living population had “major wounds” on the back or tail peduncle caused by vessel propellers. Seven documented vessel strikes are known to have taken place in Canadian waters between 1987 and 2006. However, not all deaths are documented, and that some carcasses are not in good enough condition to determine the cause of death. Moreover, the morbidity and lowered productivity and longevity of animals with injuries must be taken into account when evaluating the total impact of vessel collisions.

Entanglement in fishing gear

Fishing gear has been a hazard to western North Atlantic right whales for at least a century. Several analyses have demonstrated that interactions with fishing gear are an important factor in retarding recovery (Kraus 1990; Kenney and Kraus 1993; Knowlton and Kraus 2001). More than 70% of all living right whales have scars consistent with entanglement, and scarring rates may have increased during the 1990s (Knowlton and Kraus 2001). The types of fishing gear most often implicated in right whale entanglements are from gillnet and pot fisheries (Johnson et al. 2005).

Mortality due to vessel strike and entanglement

The two dominant known threats to right whale survival are vessel strike and entanglement in fishing gear. These to threats account for all of the known human-induced mortality. For the period of 1970 to October 2006, 73 mortalities have been documented with confidence (Table 1). Of these mortalities, 8 were caused by entanglement in fishing gear, 27 were due to vessel strikes, 21 were of undetermined cause, and 17 were a result of “neonatal mortality” where the cause of death could not be connected to vessel strike or entanglement (Knowlton and Kraus 2001; Kraus et al. 2005; New England Aquarium, unpublished data). Cause of death could not be established in the undetermined cases for several reasons: the carcass was not retrieved, the carcass was too decomposed to identify a causal factor, or no obvious factor was found despite a detailed necropsy (M. Moore, Woods Hole Oceanographic Institution, pers. comm.). In addition, from 1986 to 2005, there were 61 confirmed reports of entanglements (Kraus et al. 2005). This number includes known entanglement mortalities listed above. Note that the count of entanglement mortalities (Table 1) may be negatively biased, as it is suspected that badly entangled animals may sink upon death, due to loss of buoyancy from depleted blubber reserves, and therefore escape detection. Particularly worrisome is the recent (last 2 years) deaths of six adult females, because of the loss of breeding potential (about 25 potential offspring). Three of these mortalities are known to have been caused by vessel strike and one by entanglement; another was likely struck by a vessel (Kraus et al. 2005).

Fujiwara and Caswell (2001) suggest that a sex bias exists in human-induced mortalities, wherein the survival of females in this population is significantly lower than that of males. Given that females accompanied by calves are usually observed in coastal waters where fishing gear and vessels are more common, it is plausible that adult females would be more vulnerable to the threats of vessel strike and entanglement. Coastal distribution may also lead to higher probability of sighting carcasses than for whales located offshore.

Habitat Degradation

Several authors have raised the possibility that habitat degradation may be a factor in the slow/lack of recovery in western North Atlantic right whales (Reeves et al. 1978; Kraus 1985; Gaskin 1987; Kraus et al. 2005). Several potential causes of habitat degradation have been proposed, including: exposure to marine- and land-based contaminants, exposure to excessive noise, and human-induced changes to food concentration and availability.

Contaminants

Since right whales predominantly feed at on a low trophic level (small zooplankters), they are less likely than most other baleen whales to accumulate large body burdens of organic contaminants. To date no cases of contaminants affecting the survival or reproductive success of any baleen whale population have been documented. Note that rigorous evaluation of potential effects is very difficult given that standard experimental or epidemiological approaches are not feasible.

The risk posed to right whales from endocrine disrupting chemicals has not been investigated. Because of their use of coastal habitats, it is possible that right whales are exposed to some of these chemicals from run-off, sewage outflows or other sources. Some chemicals of potential concern include: polybrominated diphenyl ethers (flame retardants), phthalate esters (plasticizers), alkylphenol ethoxylates (surfactants) and organotin compounds (anti-fouling agents; Reeves et al. 2001).

Organochlorines, especially toxaphenes, DDT, and PCBs are present in the blubber of right whales in the western North Atlantic, but the levels are not considered high enough for concern (A. Westgate, Duke Univ., pers. comm.). A recent review of studies on contaminant levels in the Bay of Fundy demonstrated that a wide array of contaminants, including those described above, are present in the environment and in the food chain (Percy et al. 1997).

Disturbance from noise and vessel activity

The effects of increased noise on marine mammals may include habituation, behavioural disturbance (including displacement), temporary or permanent hearing impairment, acoustic masking, and mortality (Richardson et al. 1995). A range of anthropogenic noise sources in the marine waters of Atlantic Canada produce sound within the frequency range detectable by right whales. Within the high-use right whale habitat areas the sources of noise of most concern to date have related to nearby or potential oil and gas exploration, whale watching vessels, the use of harassment devices in aquaculture operations and on-shore detonations. Concerns have been expressed regarding the potentially negative effects from all types of vessel noise and presence, including from whale watching activities conducted from small vessels. Vessel activity might potentially affect the whales behaviour (e.g. disturb feeding or nursing), displacing them from rich food patches, or disperse food patches located near the surface with wake or propeller wash. Scientists at DFO, St. Andrews have conducted field observations to quantitatively and qualitatively evaluate the response of whales to many forms of vessel traffic. Analysis of these data is pending.

It has been suggested that the constant noise from shipping in the North Atlantic has habituated right whales to vessel sounds, making them less likely to avoid oncoming vessels. In addition, higher levels of ambient noise may have made it more difficult for of right whales to hear mating calls over large distances, perhaps reducing mating opportunities. Recently, Nowacek et al. (2004) tested the response of individual right whales to controlled sound exposures. These sounds included recordings of vessel noise, right whale social calls, and a signal designed to alert the whales. Nowacek et al. (2004) found that the whales reacted strongly to the alert signal, mildly to the social sounds, but showed no response to the sounds of approaching vessels.

Several studies have demonstrated behavioural responses in baleen whales in relation to exposure to seismic air guns used in petroleum exploration (DFO 2004). Seismic operators in Atlantic Canada are required to use several methods to mitigate potential disturbance, including “ramp-up” procedures, to encourage species such as marine mammals to move away from survey areas, and “shut down” procedures when a species is identified as being too close to survey. Noise from offshore hydrocarbon production platforms and exploration drilling may also be of concern as they generally tend to be of low frequency (<500 Hz) (Richardson et al. 1995). No direct studies have been undertaken in Canadian waters to investigate the effects of non-vessel noise on right whales.

Changes in food supply

Kenney et al. (1986) suggested that inadequacy of food resources could lead to either a reduction in individual growth rates, thus lengthening the time required for sexual maturation, or insufficient blubber reserves in females to sustain pregnancy or lactation, resulting in high calf mortality. Whether either of these changes is occurring in the western North Atlantic right whale population is uncertain. Global climate change could be affecting both the local spring and summer distribution of right whales in the Gulf of Maine (Kenney 1998a) and the calving rate of the western North Atlantic population (Kenney 1998b).

Aggregate total mortality and contrast to population target

Human-induced mortality is the dominant known source of known mortality, and is the most likely factor in the decline of population growth rate to less than replacement ($\lambda<1$).

Likelihood Critical Habitat is limiting recovery to target

Difficult to determine, but appears unlikely. A robust, quantitative recovery target has not been established for this species. In the earlier section describing Critical Habitat it was noted that the Bay of Fundy habitat maybe near or at carrying capacity in some years, and that the availability of additional habitat will be necessary to support substantial population growth. Knowledge is lacking concerning amount and location of potential Critical Habitat outside of the Bay of Fundy and Roseway Right Whale Conservation Areas, but the summering location(s) of up to a third of the current population are unknown.

Threats to Critical Habitat

Potential threats to Critical Habitat have been listed in Table 2. In this paper direct threats to individual whales (e.g. cause direct mortality like vessel strike) are differentiated from threats to CH.

If one accepts the definition of Critical Habitat proposed in this paper, then threats to Critical Habitat will have to somehow prevent or impede the production of interannually predictable, highly concentrated, high energy layers of right whale prey during the summer and early autumn period when right whales are in Canadian waters, or right whales to abandon the area in question. This implies that such threats must either cause direct mortality on prey field, somehow alter the oceanographic and bathymetric features that lead to prey aggregation, or exclude whales from the area. Other than fishing or large scale, permanent alteration of the seabed, few human activities have the power to cause such changes.

Some potential threats may include:
- Vessel noise
- Seismic surveys
- Oil and gas development
- Energy development using tidal or current sources
- Invasive species that predate on or compete with right whale prey
- Contaminants/pollution
- Changes in food supply
- Climate change

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Table 1: Summary of the attributed causes of reliably recorded right whale mortalities (73 cases) for the period of 1970 - January 2006. The count of entanglement mortalities may be negatively biased, as it is suspected that badly entangled animals may sink upon death, due to loss of buoyancy from depleted blubber reserves, and therefore escape detection.

Vessel strike	Entanglement	Unknown	Neonatal
27 mortalities ?? suspected	8 mortalities 12 suspected 8 currently entangled 33 now gear free 2 unidentifiable	21 mortalities	17 mortalities

Table 2: List of demonstrated and potential threats to individual North Atlantic right whales and their Critical Habitat in Canadian waters ("D": threat affects whales directly; "CH": threat affects Critical Habitat).

	Documented	Potential
Imminent or occurring	Vessel strike (D) Entanglement in fishing gear (D)	Vessel noise (CH) Seismic surveys (CH) High energy, mid-frequency sonar (D) Oil and gas development (CH) Vessel proximity and disturbance (D)
Hypothetical (may or may not be occurring at present)		Energy development using tidal or current sources (CH) Invasive species (predate on or compete with right whale prey) (CH) Contaminants/pollution (D, CH) Changes in food supply (D, CH) Climate change (D, CH)

Figure 1: Range of western North Atlantic right whale. Figure 1 is drawn directly from the draft update of the western North Atlantic right whale draft Recovery Strategy.

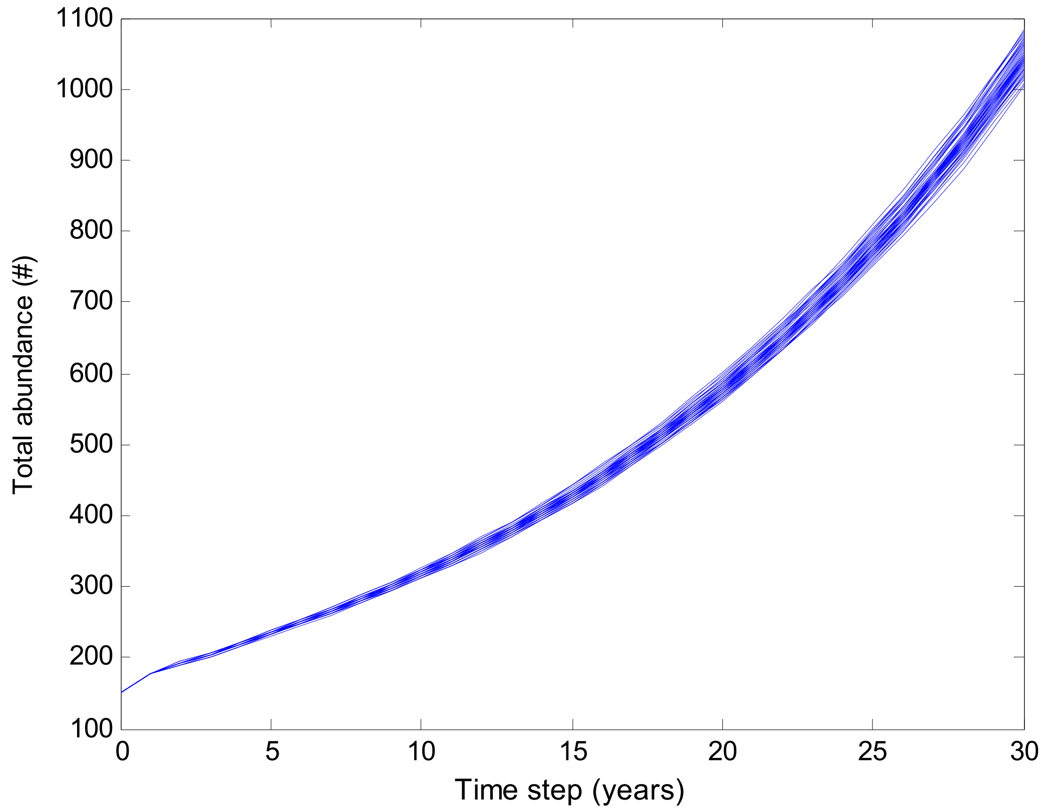

Figure 2: Model scenarios of population trajectory when right whales are exposed only to natural mortality.

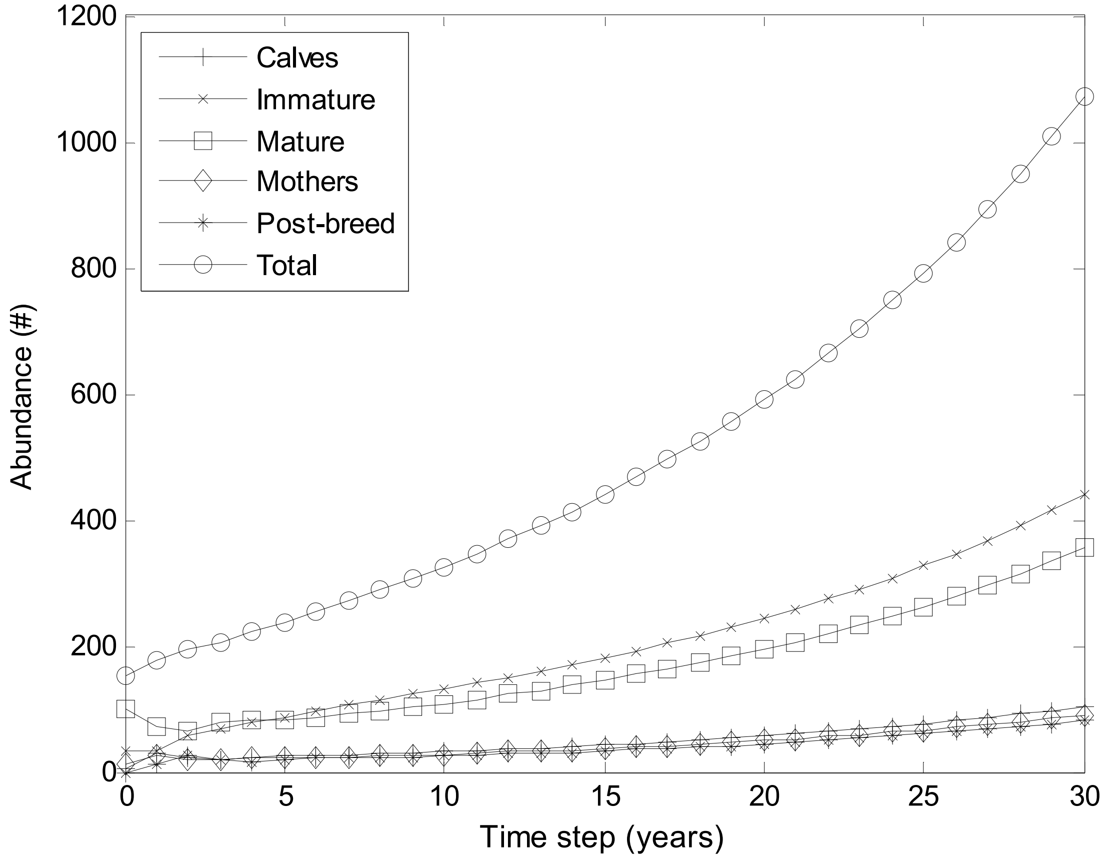

Figure 3: Example single run of population simulation exhibiting trends in all population stages.