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Study of Baleen Whales' Ecology and Interaction with Maritime Traffic Activities to Support Management of a Complex Socio-Ecological System

par

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Résumé

La gestion du milieu marin pour de multiples usages est une problématique de plus en plus en complexe. La création d'aires marines protégées (AMP) a été désignée comme étant une stratégie efficace afin de concilier la conservation avec les autres usages. Cependant, pour atteindre les objectifs de conservation, un plan de gestion bien défini de même qu'un programme de suivi efficace doivent être instaurés. En 1998, le parc marin du Saguenay–Saint-Laurent (PMSSL) a été créé afin de protéger plusieurs écosystèmes important de l'Estuaire du Saint-Laurent. Une industrie d'observation en mer de baleines en pleine croissance était déjà établie dans la région, qui est également traversé par une voie de navigation commerciale importante. Treize espèces de mammifères marins sont présentes dans la région, parmi lesquelles, quatre espèces de rorquals sont le centre d'intérêt du présent travail : le petit rorqual (*Balaenoptera acutorostrata*), le rorqual commun (*Balaenoptera physalus*), le rorqual à bosse (*Megaptera novaeangliae*) et le rorqual bleu (*Balaenoptera musculus*). La réduction des risques de collision et des perturbations du comportement susceptibles d'entrainer des conséquences physiologiques constitue un des enjeux majeures pour la conservation des baleines dans cette région. Avant de s'intéresser aux impacts du trafic maritime, des questions de base doivent être étudiées: Combien de baleines utilisent le secteur? Où sont les zones de fortes concentrations? Pour répondre à ces questions, des données d'échantillonnage par distance le long de transect linéaire sur une période de quatre ans (2006-2009) ont été utilisées pour estimer la densité et l'abondance et pour construire un modèle spatiale de la densité (MSD). Les espèces les plus abondantes sont le petit rorqual (45, 95% IC = 34-59) et le rorqual commun (24, 95% IC=18-34), suivi du rorqual bleu (3, 95% IC=2-5) et du rorqual à bosse (2, 95% IC=1-4). Les modèles additifs généralisés ont été utilisées afin de modéliser le nombre d'individus observé par espèce en fonction des variables environnementales. Les MSD ont permis l'identification des zones de concentration de chaque espèce à l'intérieur des limites de la portion de l'estuaire maritime du PMSSL et à valider les abondances estimées à partir des recensements systématiques. De plus, ils ont validé la pertinence de la zone de protection marine de l'estuaire du Saint-Laurent proposée (ZPMESL) pour la conservation du rorqual bleu, une espèce en voie de disparition. Un exercice d'extrapolation a également été effectué afin de prédire les habitats du rorqual bleu à l'extérieur de la zone d'échantillonnage. Les résultats ont montré une bonne superposition avec des jeux de données indépendants. Malgré la nature exploratoire de cet exercice et dans l'attente de meilleures informations, il pourrait servir de base de discussion pour l'élaboration de mesures de gestion afin d'augmenter la protection de l'espèce. Ensuite, les systèmes d'informations géographiques ont été utilisés afin de vérifier le degré de chevauchement entre la navigation commerciale et les résultats des MSD de chaque espèce et l'exercice d'extrapolation. Les analyses ont identifiées les zones de forte cooccurrence entre les navires et les rorquals. Ces résultats démontrent la pertinence des mesures de gestion récemment proposées et ont mené à une recommandation d'ajustement de l'actuel corridor de navigation afin de diminuer le risque de collision. Finalement, le chevauchement avec l'industrie d'observation de baleines a été caractérisé avec des données d'un échantillonnage à partir de points terrestres conduit de 2008 à 2010. Bien que toutes les espèces de rorquals aient été suivies, seulement les résultats concernant les rorquals bleus et les rorquals à bosses sont présentés ici. Pour les rorquals bleus, 14 heures de données d'observation ont été analysées. Les rorquals bleus étaient exposés aux bateaux (<1 km), principalement les zodiacs commerciaux, dans 74 % des intervalles de surface (IS) analysés. L'exposition continue était de 2 à 19 IS et le nombre moyen de bateaux à l'intérieur d'un rayon de 1 km était 2.3 (±2.7, max=14). Lorsqu'en observation de l'animal focal, tous les bateaux commerciaux ont utilisé la zone à l'intérieur de 400 m, enfreignant ainsi le règlement qui prescrit une distance de retrait minimale de 400 m dans le cas d'espèces en voie de disparition. De plus, la variance du taux respiratoire de chaque individu était corrélée avec le pourcentage d'exposition au bateaux (0.73, $p<0.05$) suggérant une modification comportementale susceptible d'entrainer des conséquences physiologiques. Bien que le rorqual à bosse n'ait pas un statut de conservation critique, sont comportements en fait une cible importante de l'industrie d'observation. Un total de 50.4 heures d'observation du rorqual à bosse a été analysé. Les rorquals à bosse étaient exposés aux bateaux, principalement aux zodiacs commerciaux, pendant 78.5% du temps d'observation. Le nombre moyen de bateaux dans un rayon de 1 km était de 1.9 (±2.3, max=22). L'exposition cumulative aux activités d'observation de baleines peut avoir des conséquences à long terme pour les rorquals. L'application du règlement et des mesures pour augmenter la sensibilisation et le respect de la règlementation actuelle sont nécessaires. Des suggestions pour améliorer la règlementation actuelle sont proposées. Ce travail présente pour la première fois des estimés d'abondance pour l'aire d'étude, améliore les informations disponibles sur les zones de fortes concentrations, donne un appui à l'établissement d'un plan de zonage adéquat à l'intérieur des limites du PMSSL et souligne l'importance de l'établissement de la ZPMESL proposée. Par sa revue compréhensive de la question du trafic maritime en lien avec les rorquals présents dans l'estuaire, cette étude fournit des informations précieuses pour la gestion de ce système socio-écologique complexe.

Mots-clés : Rorquals, estimés d'abondance, Modèle spatiale de densité, trafic maritime, industrie des observations de baleines, Saint-Laurent, gestion, aire de protection marine

Abstract

Management of the marine environment for multiple usages has become increasingly complex. The creation of Marine Protected Areas (MPAs) has been pointed out as a successful strategy for combining conservation with other uses. However, to attain conservation goals, a well-defined management plan and a robust monitoring program need to be set. In 1998, the Saguenay St. Lawrence Marine Park (SSLMP) was decreed to protect important ecosystems of the St. Lawrence River Estuary. A growing whale watching industry was already established in the area which is also crossed by an important shipping lane. Thirteen marine mammal species occur in the area, among them, four baleen species, which are the focus of the present work: minke whales (*Balaenoptera acutorostrata*), fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*) and the blue whales (*Balaenoptera musculus*). Whales' protection in this area of intensive marine traffic is of concern due to a high collision probability and induced behavioral and physiological changes. Before addressing the effects of the marine traffic, some basic questions needed to be answered: How many baleen whales use the area? Where are their core areas? To answer that, line-transect distance-sampling data collected over four years (2006-2009) were used to estimate density and abundance and to build a spatial density model (SDM). The most abundant species were minke (45, 95% CI=34-59) and fin whales (24, 95% CI=18-34), followed by blue (3, 95% CI=2-5) and humpback whales (2, 95% CI=1-4). Generalized additive models were used to model each species count as a function of space and environmental variables. The SDM allowed the identification of each species core area within the marine portion of the SSLMP, and corroborated the abundance estimates derived from design-based methods. In addition, it corroborated the relevance of the proposed St. Lawrence Estuary Marine Protected (SLEMPA) Area to the conservation of essential habitats of the endangered blue whale. An extrapolation exercise was performed to predict blue whales' habitats outside the surveyed area. Despite its exploratory nature, the results showed a good match with independent data sets and in the lack of better information could guide the discussion of management measures to enhance species' protection. Next, Geographic Information System capabilities were used to verify the degree of overlap between the navigation corridor and the resulting SDM of each species and the extrapolation model. The analysis highlighted areas of important co-occurrence of whales and ships, corroborated the adequacy of recently proposed management measures and resulted in a recommendation of adjustment to the current shipping lane in order to decrease collision risk. Finally, the overlap with the whale watching industry was characterized with data from a land-based survey conducted from 2008 to 2010. Although all baleen whale species were tracked, here only results of blue and humpback whales were presented. For blue whales, data from 14 hours of observation were analyzed. Whales were exposed to boats, mainly commercial zodiacs, in 74% of their surface intervals (SI). Continuous exposure ranged from 2 to 19 SI and the mean number of boats within a 1 km radius was 2.3 (±2.7, max=14). A complete lack of compliance with the current whale watching regulations was observed. Additionally, individual blow rate variance was correlated with percentage of exposure to boats (0.73, $p<0.05$). Although humpback whales do not have a critical conservation status, their intrinsic behaviour makes them a major target to the industry. A total of 50.4 hours of humpback whale observation was analysed. Whales were exposed to boats, mainly commercial zodiacs, during 78.5% of the observation time. The mean number of boats within a 1 km radius was 1.9 (±2.3, max=22). The cumulative exposure to whale watching can have long-term consequences for whales. Law enforcement and measures to raise awareness and compliance to current regulations are urgently needed. Suggestions to improve the current regulation were provided. The present work presents the first abundance estimates for the study area, refines the available information on baleen whales core areas, provides support to the establishment of an adequate zoning plan within the SSLMP and stresses the relevance of the SLEMPA. In addition it provides an in depth overview of the marine traffic issue and provides valuable information to support management of this complex socio-ecological system.

Keywords : baleen whales, abundance estimates, spatial density model, marine traffic, whale watching, St. Lawrence, management, marine protected area.

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Acronym list

AIC: Akaike Information Criterion
AIS: Automatic Identification System
asl: above sea level
BR: Breathing rates
CDS: Conventional Distance Sampling
CV: coefficient of variance
D: density of individuals
df: degrees of freedom
DS: density of groups
DBM: Design based methods
DFO: Department of Fisheries and Oceans
ESW: Effective strip width
FF: Focal-follow
FHAMIS: Fisheries Habitat Management Information System
GAM: Generalized Additive Model
GCV: General Cross Validation score
GIS: Geographic Information System
GOF: Goodness of Fit test
GPS: Global Positioning System
GREMM: Groupe de Recherche et Éducation sur les mammifères marins
GSL: Gulf of St. Lawrence
IFAW: International Fund for Animal Welfare
IUCN: International Union for Animal Welfare
IWC: International Whaling Commission
LBWW: Land-based whale watching
LCH: Laurentian Channel head
LOMA: Large Oceanic Marine Area

MBM: Model based methods

MCDS: Multiple-covariate Distance Sampling

MICS: Mingan Island Cetacean Study

MM: *Mer et Monde*

MPA: Marine Protected Area

N: abundance

SARA: Canadian Species at Risk Act

SD: Standard deviation

SDM: Spatial density model

SES: Socio-ecological system

SLRE: St. Lawrence River Estuary

SSLMP: Saguenay St. Lawrence Marine Park

TSS: Traffic separation scheme

VIF: variation inflation factor

WW: Whale watching

À todos os filhos. E aos filhos dos filhos. E filhos dos filhos…dos filhos….dos filhos. Filhos da mãe Terra. Filhos que seguem na busca por uma vida plena e em harmonia com todos of filhos dos filhos de todos os seres do Universo.

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Chapter 1

Introduction, Objectives, Study area and Target Species

1.1 Introduction

Records of human-whale interactions date to ancient times. The first records of whale hunting date from 1000 B.C., by Phoenicians in the Mediterranean Sea (Reeves *et al.* 2002). Since this time, our relation with marine mammal species has passed through different phases. Marine mammals have inspired the development of myths (mermaid), furnished oil for lighting and skin for clothing. After a period of intensive hunting, in modern days, they constitute a conservation symbol, used as sentinel, umbrella, or flag species in different parts of the planet (Aguirre and Tabor 2004; Bonde *et al.* 2004). Despite this, the increasing development of human societies still poses many treats to the environment in which cetacean species have evolved.

Nowadays, human societies occupy all the biomes (Ellis and Ramankutty 2008) and the coastal zone is amongst the most modified areas (Bollmann *et al.* 2010). A total of 755 of the mega-cities with populations over ten million are located in the coastal zones and 90% of the fisheries occur in coastal waters (Bollmann *et al.* 2010). As the human footprint enlarges, humanity is challenged to develop and deploy understanding of large scale commons governance to ensure sustainability (Dietz *et al.* 2003).

Successful adaptive strategies for ecosystem management include 1) building knowledge and understanding of resource and ecosystem dynamics, 2) developing practices that interpret and respond to ecological feedback, and 3) supporting flexible institutions and organisations and adaptive management processes (Berkes and Folkes 1998; Olsson *et al.* 2004). The present work aims to support the adaptive management of the St. Lawrence River Estuary (SLRE) ecosystem and particularly the conservation of baleen whale species in that system, by addressing points (1) and (3).

The SLRE is a complex socio-ecological system (SES). By definition a SES is an ecological system intricately linked with and affected by one or more social systems (Gallopin *et al.* 1988; Shaw *et al.* 1992). The SLRE is a rich ecosystem, a millenary habitat for different marine mammal species and a place where many social systems have evolved. Among the social systems that are intricately linked with the marine mammals in the

SLRE, two are of essential importance: the maritime traffic and the whale watching (WW) industry. Even if these social systems are quite different they use the SLRE for navigation purposes and their activities pose similar threats to cetacean species.

Noise pollution and collision risk are direct consequences of high levels of maritime traffic. Noise pollution can trigger short-term responses and can have long-term consequences for cetacean species (Richardson *et al.* 1995; Weilgart 2007). Short-term response may trigger serious population consequences or they may be insignificant, and on the other hand, long-term impacts may occur in the absence of observable short-term reactions (Weilgart 2007). In addition, the impact of noise pollution may be magnified when individuals show high site fidelity (Corkeron 2004; Bejder *et al.* 2006; Lusseau and Bejder 2007; Schaffar *et al.* 2010). In its turn, ship strikes can jeopardise the viability of small populations of cetacean (Fujiwara and Caswell 2001).

1.1.1 Maritime traffic effects on cetacean species

Reactions to boats are mainly a reaction to the sound they produce. Sound is a compression wave that causes particles of matter to vibrate as it transfers from one to the next (Hatch and Wright 2007). Speed of sound in seawater is the same for all frequencies, but varies with aspects of the local marine environment such as density, temperature, and salinity. The latter is of high importance in estuarine ecosystems (Hatch and Wright 2007). Depth and substrate characteristics have also an important role in sound propagation.

Marine mammals have evolved to use sound as a means of communicating, finding prey and sensing their environment. They are even capable of long-distance communication by using the oceanographic characteristics of the ocean. The sound channel (SOFAR channel), as it is called, occurs at a depth of about 800-1000 m at mid-latitudes. But its depth varies from over 1600 m in the warmest waters of the world to 100 m in colder waters and can even reach the surface at the ice edge, becoming a surface sound channel that allows long-distance communication among animals (Hatch and Wright 2007). In feeding areas, long distance communication might have an important role for baleen whales. As the food resource is patchily distributed, communicating a found patch to conspecifics might benefit the population on a long-term basis (R. Sousa-Lima, personal communication).

However, the amount of human-related sound in the oceans has increased over a very short time frame in evolutionary terms, providing only a few generations for species to adapt (Hatch and Wright 2007). With seismic surveys and naval exercises, marine traffic is among the three main sources of noise production at sea (Richardson *et al.* 1995). The increase of propeller-driver vessels has caused a rise of low-frequency ambient noise of approximately 3 dB/decade over the past 50 years (Hatch and Wright 2007).

Noise is a ubiquitous stimulus with the potential to act as a stressor (Wright *et al.* 2007). Boat noise can affect cetacean species in different manners: it can mask important sounds, induce vocal behaviour change, cause hearing loss, and confound animal's decision-making besides having cumulative physiological effects (Richardson *et al.* 1995; Bateson 2007; Weilgart 2007). This could happen through interference with their ability to detect calls from conspecifics, echolocation pulses, or other important natural sounds (Richardson *et al.* 1995). Reactions can range from brief interruptions of normal activities to short or long-term displacements from noisy areas. Previous research indicates that gray (*Eschrichtius robustus*), humpback (*Megaptera novaeagliae*) and bowhead (*Balaena misticetus*) whales may have reduced their utilization of certain heavily disturbed areas (Richardson *et al.* 1995), and that they moved away from preferred feeding areas when disturbed by vessels (Baker and Herman 1989; Borggaard *et al.* 1999).

Mysticetes species, which include all the whales focused on in this study, produce and have ears well adapted to receive low frequency sounds (Croll *et al.* 2001). Low-frequency vessel noise often masks fin whale (*Balaenoptera physalus*) social sounds, and higher-frequency outboard noise masks minke whale (*Balaenoptera acutorostrata*) sounds (Richardson *et al.* 1995). Studies of the songs of humpback whales approached by boats indicate that the durations of some song elements are altered (Norris 1994; Sousa-Lima *et al.* 2002) and that the vocal behaviour could be interrupted (Tyack 1981). The consequences of this disruption on individuals and the population are poorly understood. It may result in disruption of social ordering, sexual behaviour, care of the young and of cooperative activities (Richardson *et al.* 1995). In an Alaskan feeding ground, it was detected an increase in the rate and repetitiveness of sequential use of feeding call types by humpback whales associated with noisy areas (Doyle *et al.* 2008). Furthermore, strong sounds might cause temporary or permanent reductions in hearing sensitivity (Richardson *et al.* 1995). Also, a noisy environment can affect animal decision-making by masking the incoming information completely, partially or rendering it ambiguous. Besides, it can generate an emotional state of fear or anxiety, which could change their decision-making and increase collision risk (Bateson 2007).

To date, much still needs to be done in order to understand the degree to which human activities (such as anthropogenic noise) induce physiological and behavioural responses, which ultimately could result in changes of population dynamics such as reduced yearly survival and fecundity (Wintle 2007). However, we are beginning to realise that non-lethal impacts of human disturbance can also have serious conservation implications (Wright *et al.* 2007) . Possibly the most important of non-lethal impacts arises from the prolonged or repeated activation of the stress response, and its likelihood to induce chronic stress. Chronic stress is linked to numerous conditions in humans, including coronary disease, immune suppression, anxiety and depression, cognitive and learning difficulties, and infertility (Wright *et al.* 2007). The conceptual model developed by the US National Research Council (2005) provides a complete overview linking sound to short-term effects at the individual level that could result in long-term effects at the population level (Figure 1).

Besides the secondary effects of noise pollution, marine traffic brings with it an intrinsic collision risk (Richardson *et al.* 1995). These factors may explain, at least in part, why some species have not recovered after protective measures have been put into place (Wright *et al.* 2007), as in the case of the St. Lawrence River Estuary beluga whale (*Delphinapterus leucas*) population, which does not show signs of recovery in the last 20 years (MPO 2011).

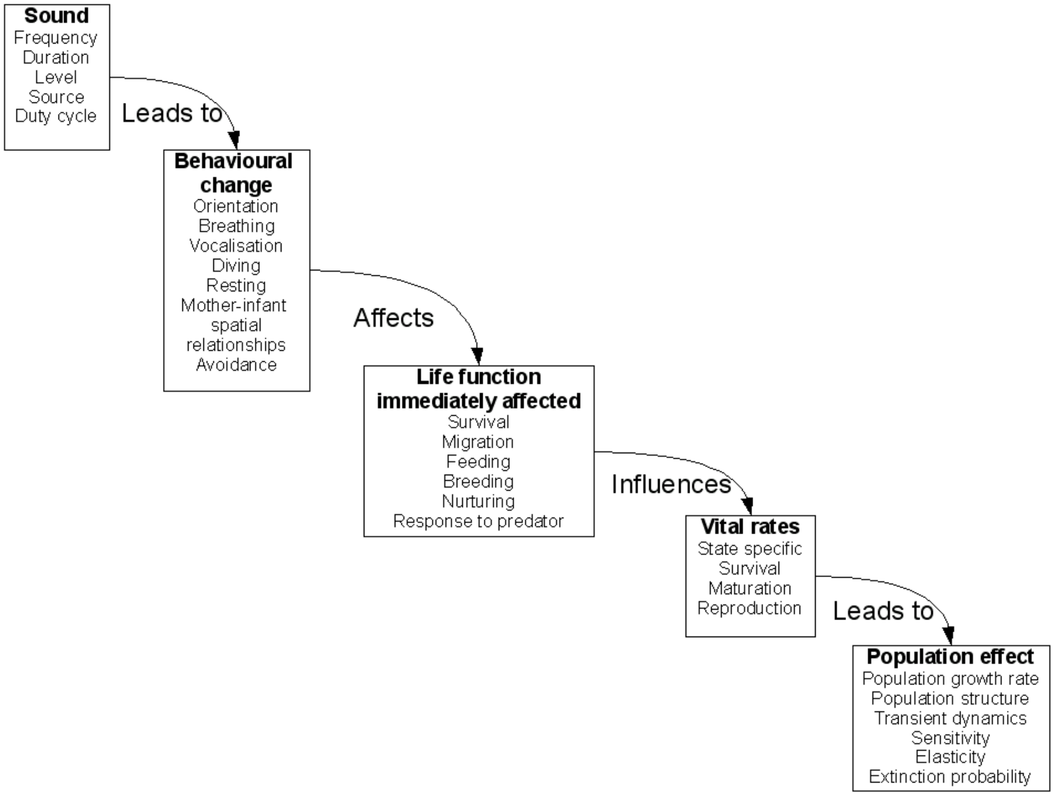


Figure 1. Conceptual model of the population consequences of acoustic disturbance on marine mammals (National Research Council (NRC) 2005).

In recent years, a great effort to measure the impact of large ship traffic on cetacean species is ongoing (IWC 2009). However, most collision events are still unreported. Ritter (2009) made a first search for collision events with sailing vessels by using an Internet form. A total of 81 collisions and 42 near misses were reported, spanning from 1966 until 2008 and from different parts of the world. Vessel type and speed as well as circumstances of the incident varied widely, but most often monohulls were involved, predominantly sailing at speeds between 5 and 10 knots. Most reports referred to "large whales". Trends involving other boat types are not yet available.

Among the eleven species known to be hit by large ships, fin whales are struck most frequently; right whales (*Eubalaena glacialis* and *E. australis*), humpback whales, sperm whales, and gray whales are hit commonly (Laist *et al.* 2001). In some areas, one-third of all fin and right whale strandings appear to involve ship strikes. Lethal or severe injuries are caused by ships 80 m or longer since whales usually are not seen beforehand or are seen too late to be avoided and most lethal or severe injuries involve ships travelling 14 knots or faster (Laist *et al.* 2001). It was demonstrated that the greatest rate of change in the probability of a lethal injury to a large whale occurs between vessel speeds of 8.6 and 15 knots where the probability of a lethal ship strike increases from 0.21 to 0.79 (Vanderlaan and Taggart 2007).

Most ship strikes reported with cetaceans occurred in the North Atlantic (Laist *et al.* 2001; Van Waerebeek and Leaper 2008; Ritter 2012). Panigada *et al.* (2006a) review ship collision records for the relatively isolated population of fin whales in the Mediterranean Sea from 1972 to 2001. Out of 287 carcasses, 46 individuals (16.0%) were certainly killed by boats. The minimum mean annual fatal collision rate increased from 1 to 1.7 whales/year from the 1970s to the 1990s. Fatal strike events (82.2%) were reported in or adjacent to the Pelagos Sanctuary, an area characterized by high levels of traffic and whale concentrations. Besides, among 383 photo-identified whales, 9 (2.4%) had marks that were attributed to a ship impact. In the St. Lawrence, many whales present such marks, although the exact proportion of affected animals is unknown. Among the blue whales photo-identified in the Gulf of Saint Lawrence (GSL), 16% bear scars that were likely to be caused by collisions with vessels (Ramp *et al.* 2006).

Local measures to mitigate ship strike have been suggested and/or have been undertaken in different places. The reduction of collision risk between commercial ships and the North Atlantic right whales have be the focus of a multi-lateral effort, which involved in depth data analysis, real time monitoring of whales and boat trajectories and the modification of shipping routes (Kraus *et al.* 2005; Merrick and Cole 2007; Vanderlaan *et al.* 2008). At the Pelagos Sanctuary, many studies suggest the use of real-time monitoring of whale presence to inform management strategies such as the modification of ferry routes and/or speed reductions due to high co-occurrence rates, mainly with fin whales (Panigada *et al.* 2006b; David *et al.* 2011). Modification of shipping lanes was suggested as a measure to improve humpback whale protection on their Brazilian breeding ground (Martins 2004) and in Panama (IWC 2012). At the Glacier Bay National Park and Reserve (Alaska), speed reductions were suggested as an effective measure to reduce collision risk and a temporary speed limit of 13 knots during the humpback whale occurrence season was adopted (IWC 2007; Harris *et al.* 2012). The same speed limit was adopted in the Strait of Gibraltar from 2007 on, and a lane modification was also implemented (IWC 2007). To date, boats transiting within the SLRE have their speed limited to 25 knots while crossing the Saguenay–St. Lawrence Marine Park (SSLMP), and boats engaged in whale watching activities should limit their speed to 10 knots while inside an observation zone / area (SOR/2002-76).

As large boats pass through an area of great importance for cetacean conservation, their speed matters not only due to the risk of collision, but also due to the almost positive correlation between ship speed and noise production. The participants of the “Global Scientific Workshop on Spatio-temporal Management of Noise” (Agardy *et al.* 2007) agreed that measures to create spatio-temporal restrictions of noise, also as part of Marine Protected Areas (MPAs) management plans, offer one of the most effective means to protect cetaceans and their habitat from the cumulative and synergistic effects of noise (Weilgart 2007). Indeed, including noise in marine spatial planning requires knowledge of noise levels on large spatial scales. Erbe *et al*. (2012) developed a simple tool based on Automatic Identification System (AIS) data to derive large-scale noise maps that allow the development of management strategies to keep quiet areas quiet and of mitigation measures to make noisy areas quieter.

Although large ships traffic and whale watching activities can induce similar effects on cetacean species, conservation measures to reduce the impact of the later are not as straightforward. Speed reduction as a measure to reduce collision risk and noise production can be applied to all kinds of boats. However, as whale watching activities are directed towards cetacean species, measures to minimise its effects have to include general and specific measures. The specific measures depend on the target species, their main activity in the area, and the characteristics of the industry that targets them, among others.

Besides the effects of noise production and collision risk exposed above, whale watching activities can also induce changes in movement pattern, respiratory behaviour, and even cause distribution shifts. Modification of movement parameters and breathing rates are usually concomitant. By using multiple linear regression analysis it was observed that humpback whales breeding at New Caledonia significantly increased their dive time from 2.7 (±2.4) to 3.1 min (±1.9), and decreased the linearity of their path when boats were present within 1000 m of the animals. The effect on linearity also proved to increase with the number of boats (Schaffar *et al.* 2010). Similar results have been reported for humpback whales in other breeding areas (Scheidat *et al.* 2004; Morete *et al.* 2007), for orcas (Bain *et al.* 2006), and sperm whales (*Physeter macrocephalus*) (Richter *et al.* 2006), to list a few. While changes in movement and breathing pattern are a short-term behavioural impact, it is also likely to increase energetic costs, which could have longer-term conservation implications (Lynas 1994; Constantine *et al.* 2004; Scheidat *et al.* 2004; Bejder *et al.* 2006; Boye *et al.* 2010; Schaffar *et al.* 2010; Visser *et al.* 2010; Steckenreuter *et al.* 2011).

1.1.2 Large ship traffic and whale watching activities within the SLRE

The SLRE is the main navigation entry of the eastern Canadian Coast. Large ship traffic within the SLRE is intense and might double in the coming years (Ircha 2005). The only information to date to characterize the maritime traffic is restricted to the SSLMP. Chion and colleagues (2009) provided the first comprehensive characterization of the maritime traffic within the SSLMP for the year of 2007.

In order to characterize the commercial ships traffic, Chion *et al*. (2009) used AIS data and prevision data from the Information System on Marine Navigation (INNAV) of the Canadian Coast Guard. A total of 3135 transits were made within the SSLMP from May to October 2007 by more than 650 different ships (*i.e.* cargo ships, tankers and tug/tows). The number of transits showed little fluctuation along the period (fortnights and week days) and throughout the day. However, a 9% increase in the number of transits was observed from 2003 to 2007. A similar volume of traffic was found within the Gerry E. Studds Stellwagen Bank National Marine Sanctuary in 2006 (Hatch *et al.* 2008). They registered 541 large commercial vessels and a total of 3413 transits within the Marine Sanctuary for that year.

Besides large commercial ships, Chion and colleagues (2009) also provides a complete description of the other boat types that use the area. The higher number of transits within the studied period (22 541 transits) was attributed to the ferry boats that link the villages of Baie-Sainte-Catherine and Tadoussac, at the mouth of the Saguenay River. The second component of the maritime traffic in terms of number of transits is the whale watching industry (WW). In 2007, they estimated that 13 073 excursions took place between May and October 31st.

The first WW expedition in the SLRE took place in 1971. It was organized in collaboration with the Montreal Zoological Society, used occasional charters and amounted to no more than two per year (Lynas 1990). The activity followed its natural evolution from there and in 1988, 11 whale watching boats were operating regularly in the area. At this time, the industry's gross income was estimated as 11.6 million (Lynas 1990).

Concern about the WW industry's impact on whales was already discussed in 1988, always with a greater focus on beluga whales due to the species' reduced numbers and annual occurrence. At that time, a call for a regulatory policy was proposed as a *precautionary measure* (Lynas 1990). The adoption of the Marine Activities Regulations in 2002 was an important step towards species' protection and the sustainability of WW activities. In addition, the number of boats operating under permit to practice commercial observation activities at sea inside the Marine Park was limited to a maximum of 59 as of 2003 and has remained relatively constant, although a few permits have become inactive. As for the number of excursions per day, there is a small demand for early morning excursions, but overall, the number of excursions has remained relatively constant over the years (N. Ménard, personal communication). However, the lack of commitment to the current regulation and of an effective monitoring system diminishes its effectiveness.

1.2 Objectives

Maritime traffic has increased over the last century while our knowledge about the functioning of marine ecosystems was also evolving. Ship lanes were placed to optimize benefits for transportation without taking into account ecosystem management and conservation priorities. On the other hand, in many places, former hunters became the owners of enterprises that today bring thousands of people to watch whales in the wild. And although concerns about the potential impacts of this activity have been discussed at least in the last 20 years (e.g. Forestell and Kaufman 1990; Forestell 1993; IFAW 1995; Hoyt 2001; Corkeron 2004), they are still to be fully understood.

Ecosystem-based management has been proposed as the best approach for achieving sustainability (CBD 1992; Browman *et al.* 2004) and is the main directive in most developed countries, as well as in Canada. However, for most ecosystems, clear directives for implementing ecosystem-based management have yet to be developed, particularly in Canada. Sound science to support management actions is indeed required. It was in this context that this project was elaborated.

1.2.1 General objective

Improve knowledge on the distribution and behaviour of baleen whales in the SLRE so as to provide support for stakeholders' decision-making related to marine traffic management and cetacean protection within the study area.

1.2.2 Specific objectives

1. Estimate baleen whales abundances
2. Model baleen whales distributions
3. Verify the overlap between baleen whales distribution and the main ship lanes
4. Characterise the degree of exposure of baleen whales to whale watching activities

To address these questions an existent database was used to derive density and abundance estimates (Chapter 2) and to identify the species core areas (Chapter 3). The resultant spatial density model (SDM) was used to verify the degree of overlap between the core areas used by baleen whales and ship lanes (Chapter 4). To characterize the degree of exposure of baleen whales within the SLRE to the WW industry, the second component of the maritime traffic addressed by the present study, data collected from land-based observation sites between 2008 and 2010 were used (Chapter 5 and 6). The exposures of the endangered blue whale and of the humpback whale, an important target of the local industry nowadays, were characterised. In the light of these results, management strategies to reduce the impact of the maritime traffic and decrease whales' exposure were discussed.

1.3 Study area: the marine portion of the St. Lawrence River Estuary

The Gulf of St. Lawrence is one of the five 'Large Oceanic Marine Areas (LOMA)' identified by the Canadian government for management purposes. The Gulf is a stratified semi-enclosed sea connected to the North Atlantic Ocean through the Cabot Strait to the southeast and the Strait of Belle-isle to the northeast (Figure 2). The St. Lawrence River and its tributaries are the main fluvial contributors of this system.

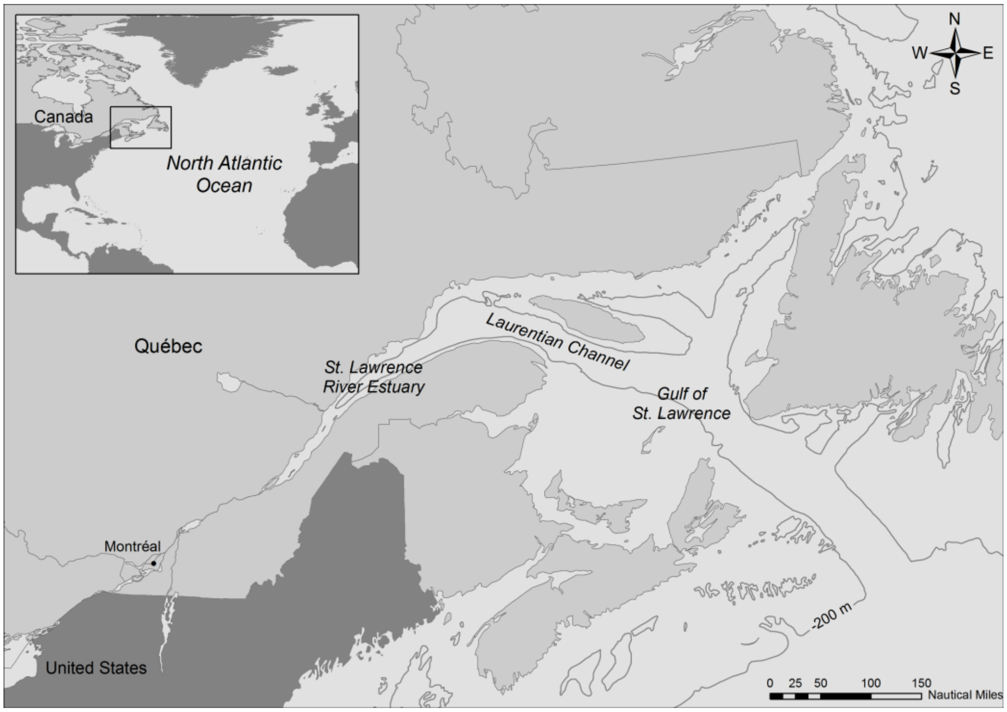


Figure 2. The study area overview showing its connection with the Gulf of St. Lawrence - one of the five 'Large Oceanic Marine Areas (LOMA)' identified by the Canadian government.

The study area is located in the marine portion of the St. Lawrence River Estuary. The area of interest comprises the marine portion of the Saguenay–Saint-Lawrence Marine Park (SSLMP) and of the proposed St. Lawrence Estuary Marine Protected Area (SLEMPA), which is in the process of creation. However, most of the data was collected within the marine portion of the SSLMP (Figure 3).

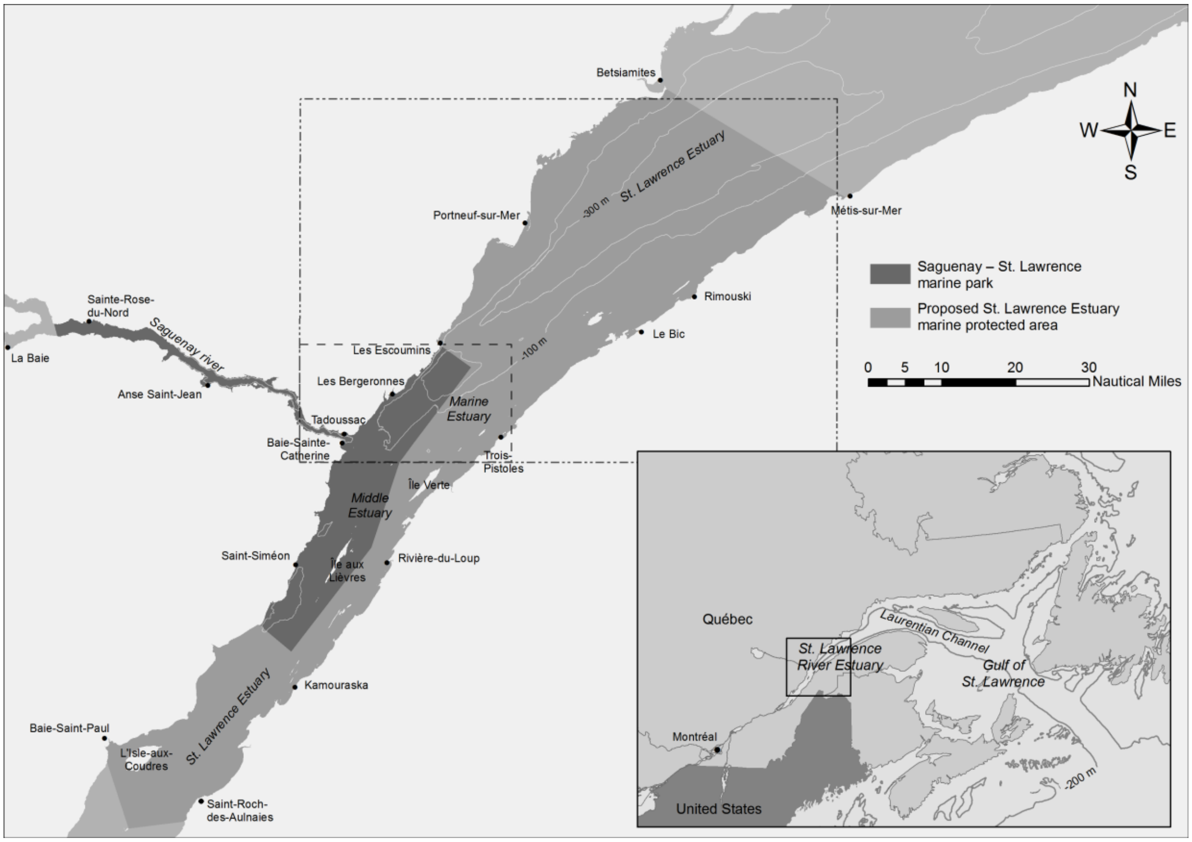


Figure 3. The marine portion of the proposed St. Lawrence Estuary Marine Protected Area (dot-dashed box) which constitutes the global study area and the marine portion of the Saguenay-St. Lawrence Marine Park (dashed box) where most of the data was collected.

The SSLMP was created in 1998, as part of a bilateral effort of the government of Quebec and Canada. It was the first MPA to be created in Quebec, and remains the only one to date. However, a network of MPAs, linking areas of ecological importance from the estuary to the Gulf, is under study, which includes the SLEMPA and Manicouagan MPA (G. Cantin, personal communication). The SSLMP encompasses 1138 km^2, and follows the northern coast from Cap-à-l'Aigle to Les Escoumins, and at the Saguenay, it comprises the region from the river mouth to Cap à l'Est (PMSSL 1995).

An important hotspot of krill of the North Atlantic Ocean is located inside the

SSLMP (Cotté and Simard 2005). An arm of the Labrador Current penetrates the deep valley that follows the northern shore margin, and at the confluence of the Saguenay and Saint Lawrence rivers a submarine bank defines the Laurentian channel's head where a localized resurgence of the Labrador cold and nutrient rich water takes place (Cotté and Simard 2005). Besides krill, schooling fishes such as capelin (*Mallotus villosus*), sand lance (*Ammodytes* sp.) and herring (*Clupea harengus*) occur in high abundance associated to this resurgence area (Ménard 1998; Simard *et al.* 2002; Simard 2009).

The GSL is characterized by high productivity and diversity. It is the habitat for more than 2200 species of invertebrates and presents also a high diversity of fish species (BAPE 2004). Also, it presents elevated marine mammal diversity. Among the 19 species occurring in the Gulf, 13 were recorded in the SSLMP area (Mitchell *et al.* 1982; Michaud *et al.* 1997), they are: Blue whale (*Balaenoptera musculus*); Fin whale (*Balaenoptera physalus*); Humpback whale (*Megaptera novaeangliae*); Minke whale (*Balaenoptera acutorostrata*); Beluga (*Delphinapterus leucas*); Harbor porpoise (*Phocoena phocoena*); Sperm Whale (*Physeter macrocephalus*); Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); White-beaked Dolphin (*Lagenorhynchus albirostris*); Orca (*Orcunus orca*); Harbor Seal (*Phoca vitulina*); Gray Seal (*Halichoerus grypus*); and Harp Seal (*Pagophilus groenlandicus*).

Pilot whales (*Globicephala melas*), which occur regularly in the GSL, used to occur in the area. Mitchell *et al.* (1982) reported a sighting in the 1970s, which consisted of a group being chased by hunters. In the 1990s, it was reported that pilot whales, white-beaked dolphin, white-sided dolphin and orcas were rarely seen west of Pointe-des-Monts (Lynas 1990). Beluga whales are resident year round in the SLRE (Pippard 1985). The present study focuses on the four baleen whale species that occur in the study area: fin, humpback, blue and minke whales. Fin and minke whales are the most frequent in the area (Mitchell *et al.* 1982; Edds and Macfarlane 1987).

1.4 Target species

The four species of baleen whales (Figure 4) that occur within the SLRE have a similar ecology and are faced with the same anthropogenic impacts. However, they have different conservation statuses and are affected in different ways by anthropogenic activities. The main threats they face are related to habitat degradation and marine traffic intensity. Development of coastal infrastructure and the possibility of a future exploitation of oil and gas in the area are of concern (Bureau d'Audiences Publiques sur l'Environnement (BAPE) 2004). Below, a summary description of the knowledge about each baleen whale species in the area is provided.

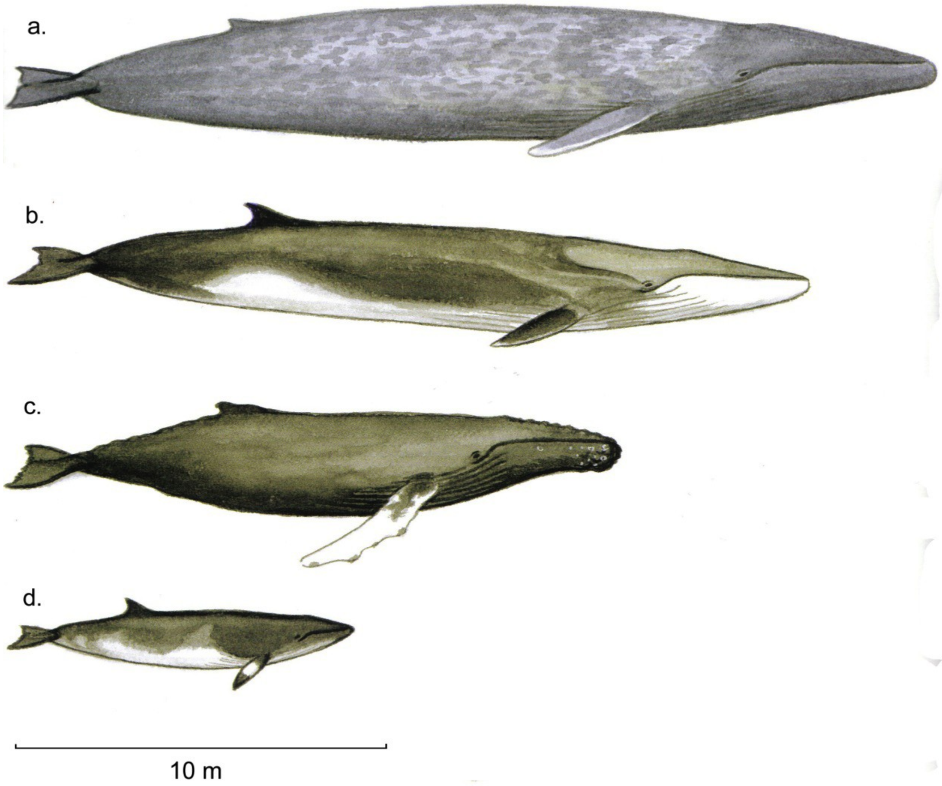


Figure 4. External morphology of the baleen whale species (a. blue whale; b. fin whale; c. humpback whale; d. minke whale) focus of the present study (Artwork: Daniel Grenier).

1.4.1 Minke whale (Balaenoptera acutorostrata)

Minke whales (Figure 5) present a cosmopolitan distribution. Recent population estimates for North Atlantic Canadian waters are of the order of 15,000 individuals (COSEWIC 2006). Although the species is regularly hunted in some northern countries, recent and current removals do not exceed replacement (COSEWIC 2006).

The species is ubiquitous in the Saint Lawrence Estuary and is the target of a long-term study ongoing since the late 1970's. Until recently, photo-identification has led to the cataloguing of over 300 animals (U. Tscherter personal communication), 70% of which were sighted in two different years. Besides fidelity to the feeding area in general, small-scale site fidelity was reported (Morris and Tscherter 2006). Among 209 individuals that were recorded in the SLRE from 1999 to 2004, 35 were classified as regular, and they corresponded to 59% of all daily-sightings along that period. Among regulars, yearly residency lasted for approximately 70 days and 25 of them presented small-scale site fidelity within the same year and in different years (12 at the Laurentian Channel Head (LCH) region, and 13 at the Fjord and mouth of Saguenay River) (Morris and Tscherter 2006).

Minke whales have a typical solitary behaviour. Different feeding techniques have been described in the St. Lawrence (Lynas and Sylvester 1988), and individual specializations were reported (Kuker *et al.* 2005). Kuker *et al.* (2005) described three surface manoeuvres prior to feeding strikes of individual whales that show strong fidelity to the mouth of the Saguenay River: head slap, lateral chin-up blow, and exhale on the dive.

Focal-follow (FF) observations of minke whales' behaviour from a zodiac allowed characterizing the breathing pattern of four behavioural states: travelling, surface feeding, near surface feeding, and deep feeding (Lynas unpublished data in Curnier and Tscherter 2006). Sequences of 25 minutes of observation on each animal were used in order to characterize its behaviour and acquire information about the corresponding breathing pattern. Surface feeding animals show no pattern in their breathing, while all other categories present a well-defined pattern that differs across behavioural category (Curnier and Tscherter 2006). At the study area, behavioural data indicate that minke whales dedicate 61% of their daily activities to feeding, and 23 % to seeking for prey (Lynas 1990).

The species is not considered as a WW target at the St. Lawrence. However, in the absence of bigger whales, they guarantee the success of many excursions mainly at the beginning and the end of the season. Not being considered as a target and not being an endangered species make them more susceptible to infractions of the current WW regulation (*e.g.* distance and speed of approach).

Figure 5. Surface feeding minke whale (*Balaenoptera acutorostrata*) (Photo: Chiara G. Bertulli/ORES).

1.4.2 Fin whale (*Balaenoptera physalus*)

Fin whales (Figure 6) are distributed over a wide part of the North Atlantic Ocean. Their occurrence is limited to highly productive areas between the ice edge and a maximum sea surface temperature of 15° C (Sergeant 1977). Even if distinct populations are recognized, further information is needed in order to define the population structure in the

North-eastern Atlantic (Sergeant 1977). Based on reported sightings and food availability, little seasonal movement takes place.

Recent studies based on contaminants (Hobbs *et al.* 2001), residency and movement patterns (Coakes *et al.* 2005; Robbins *et al.* 2007) support the hypothesis that GSL fin whales are relatively isolated from whales in the Gulf of Maine, Nova Scotia, and Newfoundland. However, limited movements occur between these areas and no evidence of genetic difference was found between the GSL and the Gulf of Maine (Bérubé *et al.* 1998). The North Atlantic fin whale population is considered as threatened (COSEWIC 2005), and no reliable population estimates have yet been produced.

In the SLRE, fin whale occurrence is seasonal. Sightings are recorded from early June through December (Mitchell *et al.* 1982; Michaud *et al.* 2008; Michaud *et al.* 2011). Photo-identification studies are conducted from Tadoussac since 1986 by the *Groupe de Recherche et Éducation sur les Mammifères Marins* (GREMM). Data collected from 1986 up to 2000 allowed the identification of 74 individuals (Giard *et al.* 2001). Among them, 22 were considered as residents (animals which returned to the area in 75% of the years after their photo-identification), 16 as regular visitors (returned in 40 -75% of the years) and 24 as sporadic visitors. Lynas (1990) mentioned never having recorded more than 40 fin whales on the same in between Tadoussac and Les Escoumins, and suggested this as a limit for a given day.

Fin whales feed on zooplankton (euphasiids and copepods) and schooling fishes, such as capelin and herring. Sand lance may also be an important prey (S. Turgeon, personal communication). Although recognized as a generalist species, specific groups of fin whales may develop a preference for certain prey species (Sergeant 1977). Usually, they exhibit solitary behaviour while feeding upon krill and a gregarious behaviour when feeding upon schooling fishes (R. Michaud, personal communication).

VHF tracking of 25 individuals was conducted from 1994 to 1996 in the SLRE. Besides a complete characterisation of the animals' diving profile, data supported the hypothesis that while in interaction with approaching boats animals change their diving behaviour (Michaud and Giard 1997; Michaud and Giard 1998). This dataset provides valuable information concerning habitat use patterns of the animals and their movement parameters.

Fin whales have been the main target of WW excursions in the SSLMP since the activity began (Michaud *et al.* 1997; Michaud *et al.* 2008; Michaud *et al.* 2011). The species' high site fidelity and residency time (GREMM unpublished data; Michaud and Giard 1998) amplify the effects of their exposure to WW boats.

Figure 6. Fin whales (*Balaenoptera physalus*) (Photo: Cris Albuquerque Martins).

1.4.3 Blue whale (Balaenoptera musculus)

Blue whales (Figure 7) are the largest animals that ever existed on Earth. They range in size to over 30 m and weigh up to 160 tons (Mackintosh 1942; Mizroch *et al.* 1984*)*. In most of their range, they are generally solitary or found in small groups (Mizroch *et al.* 1984). They prey exclusively on krill, and their occurrence is dependent upon food availability (Schoenherr 1991).

Competition with other baleen whales for krill does not seem to be the reason for their slow recovery (Clapham *et al.* 1999). The North Atlantic blue whale population is classified as “endangered” (COSEWIC 2002) due to intense harvest early in the 1900’s, followed by low population sizes and small numbers of calves (Lesage and Hammill 2003).

As for other baleen whales, seasonal migratory movements are observed, but they are not completely known to date. In the North Atlantic, two stocks are recognised for management purposes, western and eastern stocks, and both of them are considered at risk (Clapham *et al.* 1999; COSEWIC 2002). Whaling and photo-identification data suggest that blue whales found off the coast of Nova Scotia, Newfoundland, the Gulf of Saint Lawrence (GSL) and western Greenland belong to the same population (Clapham *et al.* 1999; COSEWIC 2002).

Blue whales are seen regularly in the GSL from May to December, peaking from June through August (Sears and Calambokidis 2002). Male and female occurrences in the GSL show different pattern (Ramp *et al.* 2006). The number of males peaks in August and the number of females has a first peak in August and a second one in October, closer to the breeding season. Blue whales observed at the GSL are regularly seen at the SLRE. Inside the estuary, animals tend to concentrate at its downstream portion between Les Escoumins and Portneuf (Michaud *et al.* 2008; Doniol-Valcroze *et al.* 2012). However, they usually penetrate the SSLMP area, remaining there for variable periods.

Blue whales are individually identifiable from the unique pattern of mottling on their bodies (Sears *et al.* 1990). A long term photo-identification catalogue maintained by Mingan Island Cetacean Study (MICS), a non-profit organisation in the Gulf of Saint Lawrence, had 388 distinct animals in 2002 (Ramp *et al.* 2006).

Previous studies of the surface behaviour of blue whales in the St. Lawrence provide a detailed description of their surface geometry (Mitchell *et al.* 1982; Lynas 1994). While at the surface, blue whales follow a “J” trajectory that should optimize feeding and help to keep the patch position. By re-positioning itself during the surface interval, an individual avoids doing so while submerged to feed, thus optimizing its energy budget. Studies have shown that their foraging strategy (lunge-feeding) presents a high energetic cost (Acevedo-Gutierrez *et al.* 2002; Doniol-Valcroze *et al.* 2011), and strategies to optimise foraging are of extreme importance for these animals. Attempts to avoid disrupting their surface behaviour during WW excursions at the SSLMP region were strongly recommended by Lynas (1994). Actual regulation of WW activities establishes 400 m as the distance limit to approach blue whales inside the park (SOR/2002-76).

Figure 7. Blue whale (*Balaenoptera musculus*) (Photo: Cris Albuquerque Martins).

1.4.4 Humpback whale (Megaptera novaeangliae)

The humpback whale (Figure 8) is the most studied baleen species in the world (Clapham and Mead 1999). The best available population estimate for the entire North Atlantic is 11 570 (95% CI 10290 to 13390) animals based on data from 1992-93 (Stevick *et al.* 2003). Overexploited in the last centuries, the north Atlantic population is considered as “not at risk” (COSEWIC 2003).

North Atlantic individuals migrate annually from Caribbean breeding areas to northern feeding areas (Stevick *et al.* 2003). Capable of extensive migrations of the order of thousands of kilometres and of daily displacements of the order of a hundred kilometres, they return to specific feeding sites annually (Stevick *et al.* 2006). In the North Atlantic, a recent study pointed out the existence of four main feeding aggregations separated by 900-1300 km, and within which little individual movement has been observed (Stevick *et al.* 2006).

The St. Lawrence’s humpback whales belong to the Gulf of St. Lawrence (GSL) feeding aggregation (Stevick *et al.* 2006). Occasional sightings have been reported since the early 1970s inside the estuary (Mitchell *et al.* 1982). According to Lynas (1990), from two to six whales are sighted each year in the middle estuary, and from 2000 on it has been a regular species inside the SSLMP (Michaud *et al.* 2008; Michaud *et al.* 2011)

The pattern observed inside the estuary indicates that the species is reoccupying a pre-whaling feeding area, a process governed by a matriarchal system (Weinrich *et al.* 2006). Birth takes place at low latitude breeding grounds and the female returns to its feeding ground with the newborn calf, where they will spend the summer before returning together to the breeding site (Dawbin 1966). In this process the calf learns the way to and from the feeding location. In addition, a study carried out in the Gulf of Maine suggests the existence of feeding specialisations, which would be transmitted from the mother (Weinrich *et al.* 2006). The mother would teach the calf where to feed, on which prey and with which technique. One of the humpback whales often observed at the study area is a female named “TicTacToe”, who has returned each year since 1999 (when she was first registered and classified as a juvenile) (Baleines en direct 2012). In 2007, it was first seen with a yearling of the season (“Aramis”). From this year on, “Aramis” frequents the area on a regular basis and in 2012 “TicTacToe” was recorded again with a calf. While in the area, humpback whales are the main WW target due to the species’ characteristic fluke-up dives and their singular aerial behaviour.

Figure 8. Humpback whale (*Megaptera novaeangliae*) (Photo: Catherine Dubé).

Chapter 2

Estimating baleen whales' abundance within the marine portion of the St. Lawrence River Estuary

2.1 Introduction

Knowledge of baleen whales' density and abundance is essential for conservation and management purposes. Baleen whale populations were affected in different ways during the hunting period, and to date, some are still considered at risk of extinction. Of the four species occurring within the marine portion of the St. Lawrence River Estuary (SLRE), minke and humpback whales are considered as of least concern by the International Union for Conservation of Nature (IUCN) and are not listed by the Canadian Species at Risk Act (SARA). However, fin whales are listed as endangered by the IUCN Red List (Reilly *et al.* 2008) and as vulnerable by the SARA and blue whales are considered as endangered according to both (Sears and Calambokidis 2002; Reilly *et al.* 2008)

As baleen whales recover from severe exploitation, they are faced with a wide variety of threats (Leaper and Miller 2011). Coastal development, water contamination, off-shore anthropogenic activities (e.g. increasing fisheries, maritime traffic, oil and gas exploration, to name a few) can all affect to some degree the conservation of whales. In this scenario, adequate monitoring of cetacean distribution and abundance is essential to provide stakeholders with the necessary data to inform sustainable management actions.

The baseline information on baleen whales' distribution at the SLRE was compiled by the Department of Fisheries and Oceans (DFO) and was made available through an interactive system, the Fisheries Habitat Management Information System (FHAMIS)(DFO 2011). The FHAMIS is used by the DFO and other institutions as a tool to ensure the sound management of the aquatic environment (DFO 2011). The system is composed of Geographic Information System (GIS) layers, which were built for the area based on the knowledge of experts and non-systematic survey data. It is constituted of polygons delimiting the most extremes points of occurrence for each species. However, no information about the density is available, thus preventing any in-depth analysis of habitat preference and management actions to ensure the protection of core areas. In addition, abundance estimates are not available neither within the SLRE nor in the adjacent waters.

A systematic study aiming to evaluate the intra-seasonal variation of density and abundance within the marine portion of the SLRE was conducted by the *Groupe de Recherche et Éducation sur les Mammifères Marins* (GREMM) over four years (2006 – 2011). The study focused on the area in which the whale watching (WW) industry concentrates it activities (Michaud *et al.* 1997; Michaud *et al.* 2008) and followed the line transect distance sampling protocol. To reach their goal, the GREMM opted for an optimized design (zig-zag), associated to low cost (*i.e.* small boat, single observer) and a high number of repetitions. Despite not being designed to provide a global portrait of density and abundance in the area, the resulting database provides the most reliable data available to this end.

Here, this data set was used to extract density and abundance estimates of each baleen whale species recorded during four years (2006-2009) of survey conducted by the GREMM. The analysis followed the distance sampling guideline with the derivation of global abundance estimates though the fitting of a detection function from the line transect data for each species. This study presents the first density and abundance estimate for each of the four baleen whales occurring in the area and provides recommendations to improve future work.

2.2 Material and methods

2.2.1 Design-based method assumptions

Line transect distance sampling (Hiby and Hammond 1989; Buckland *et al.* 2001) is a standard method applied worldwide to a vast number of animal species. The method provides an estimate of the number of animals in a defined area at a particular time or over a period (Hammond 2010). The basic idea of the method is to estimate the density of the target species in strips sampled by surveying along a series of transects, and to extrapolate this sample density to the entire survey area. The method relies on three main assumptions: 1) animals on the line are detected with certainty; 2) they do not react to the survey platform, and 3) measurements are exact. In addition, it is assumed that lines are placed at random within the study area and are independent of the animals' positions (Buckland *et al.* 1993; Buckland *et al.* 2001; Thomas *et al.* 2010). The last assumption is what defines the design-based method (DBM) (Thomas *et al.* 2007).

Standard analysis methods assume that on average over many repetitions, each point within the study area has the same probability of being sampled (*i.e.* equal coverage probability) (Buckland *et al.* 2001). As a consequence of this assumption, any change in frequency of animal detection with increasing distance from the line can be interpreted as a change in the probability of detection, rather than a change in true density. And also, the resulting density estimate can be applied to the whole survey area (whole study area), not just the covered strips (Thomas *et al.* 2007). Besides a random design, a minimum number of lines (or replications) are required for assessment of the uncertainty in design-based estimates (Thomas *et al.* 2007). Buckland *et al.* (2001) recommend a minimum of 10 to 20 replicates in order to have reliable variance estimates, while Thomas *et al*. (2007) considered 15 replicates as a minimum for a good design.

2.2.2 Survey area and period

The study area comprised the marine portion of the SLRE and covered 579.84 km^2 (Figure 9). Almost 70% of the study area is within the Saguenay-St. Lawrence Marine Park (SSLMP), the other 30% covers part of the St. Lawrence Estuary Marine Protected Area (SLEMPA). Data were collected from mid June to late September. Systematic surveys took place three times a week weather permitting from 2006 to 2009.

2.2.3 Survey design and searching effort

The surveys were designed and conducted by the GREMM's research team based on line-transect distance sampling methods (Buckland *et al.* 1993; Buckland *et al.* 2001). Three zigzag schemes (each with six legs, *l*) with equal angle but with differing starting points (chosen at random) were established (Figure 9). A complete survey represented approximately 55 km on effort and each leg ranged from six to 10 km. The zigzag transects were designed to cover the area from the coastline till the marine park boundary. A zigzag scheme was preferred due to the area's narrowness allowing a maximization of effort.

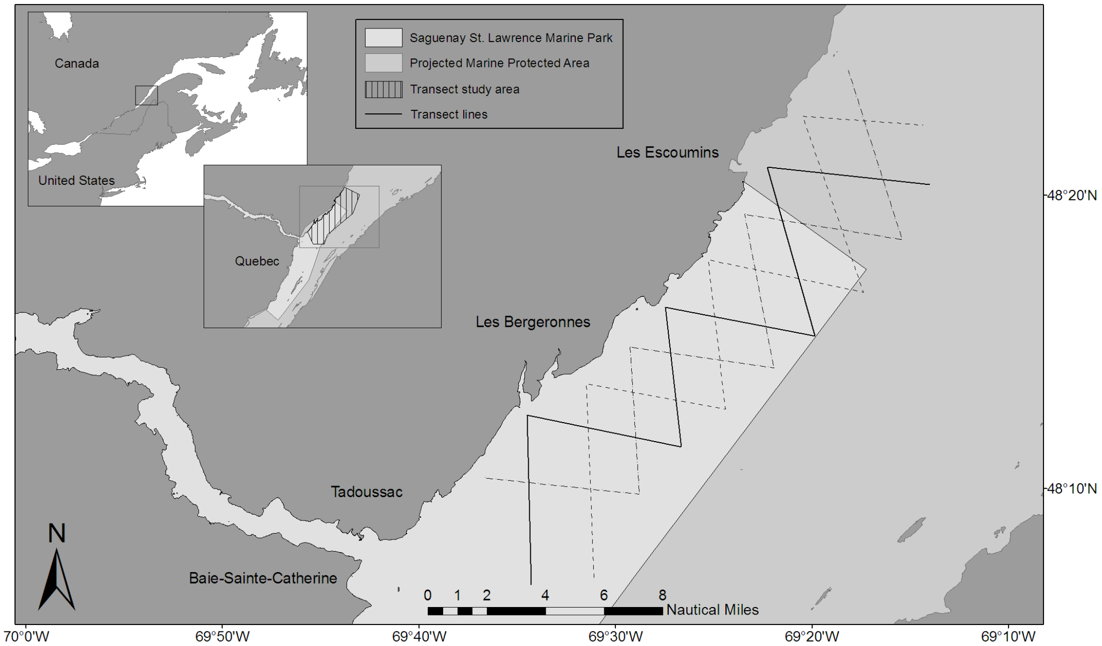


Figure 9. Transect lines designed for the systematic surveys conducted from 2006 to 2009. At each survey day a different set of lines (solid line, dashed line or dash-dot line) was monitored.

Planning meetings and training sessions were held before the beginning of the project in 2006 and before each field season. Within the same season only one observer was responsible for most surveys, minimising bias due to different observers within a year. The observer was positioned in front of the boat searching forward constantly and less often laterally and backward. Bearing was measured with a hand held electronic compass and distance was estimated visually. Observers calibrated their estimates of distance at the beginning of the season, and as often as necessary. Data was recorded on a hand held recorder and transcribed afterwards. Species, group size and general comments were registered at each sighting event. No sightings at distances greater than 2 km were recorded.

The survey was conducted onboard a Zodiac SRMN 600. The observer used a fixed platform that was 1 m above the sea level. The boat navigated at a constant speed of 15 kt and the track-line was recorded with a hand held GPS Garmin Foretrex 301. Navigation direction (up to downstream or down to upstream) varied along the season depending on meteorological conditions.

2.2.4 Data preparation

Data was explored in order to detect possible outliers, data entry error and to extract a data summary using R 2.10.1 (R Development Core Team 2009). DISTANCE 6.0 ® (Thomas *et al.* 2010) was used to fit a detection function to each species and estimate effective strip width (ESW). Perpendicular sighting data were modelled using the half normal function with cosine, simple and hermite polynomial adjustments and the hazard rate key with cosine and hermite series expansions. Variance was estimated empirically. The model that best fitted the data was selected according to the Akaike Information Criterion (AIC) (Akaike 1985) as implemented in DISTANCE 6.0. Grouping is usually needed in cases of heaping (errors in measurement) and movement prior to detection (Buckland *et al.* 2001). As distances were estimated visually, data were grouped in increasing distance intervals, which varied according to the species.

The survey was repeated up to three times a week (weather permitting), but at each survey a total of six legs or replicates were completed while the minimum number required to assess uncertainty adequately is between 10 and 20 (Buckland *et al.* 2001). Following suggestions of L. Thomas (personal communication), different repetitions of the survey were grouped in order to improve the number of surveyed lines. It was assumed that within the same week immigration and emigration did not occur and thus did not modify the true density in the area. Thus all surveys carried out within the same week were considered as a stratum in order to increase overall variance estimates. Each stratum could have up to 18 surveyed lines instead of six of each single survey. The above mentioned assumption was deemed to be a necessary and reasonable assumption in order to meet the requirements of the modeling method, and given the relatively stable presence of the species during the core summer period it is not expected to significantly affect the results.

2.2.5 Data analysis

Firstly, a conventional distance sampling (CDS) model was fitted to each species. For the species with enough recordings (n > 60-80) (Buckland *et al.* 2001) a multiple-covariate distance sampling (MCDS) model (Marques 2001; Marques and Buckland 2003; Marques and Buckland 2004) was also fitted. By using CDS we assume that the only factor influencing detection is distance, while it is known that other factors can affect it (i.e. observer, visibility conditions, Beaufort state) (Marques and Buckland 2004). These other factors are a source of heterogeneity, whose effect increases if data from different strata are pooled to fit the detection function (Marques and Buckland 2004). As data from different survey days were pooled, it is important to verify if the detection function is improved while considering the covariates.

The covariates believed to affect detection probability were incorporated into the MCDS model. Table 1 presents the adopted definitions for each covariate recorded during the field-work. A stepwise forward selection procedure was used (starting with the simplest model containing perpendicular distance only) and model selection was made based on AIC.

Table 1. Summary of available covariates considered to model the detection function along with levels description as defined in the data collection protocol.

Covariate	# Levels	Levels' description
Observer	3 levels	One for each different observer
Visibility	4 levels	1)500 m; 2)501 m-2 km; 3)2001 m-5 km; 4)>5 km
Wave height	5 levels	1)mirror; 2)<15 cm; 3)16-30 cm; 4)31-60 cm; 5)>61 cm
Cloud cover	4 levels	1)0-25%; 2)25-50%, 3)50-75%, 4)>75%

2.2.6 Estimators of density and abundance

For a complete description of the estimators implemented by the CDS and MCDS engines the interested reader shall consult the method's main references (Buckland *et al.* 1993; Buckland *et al.* 2001; Marques and Buckland 2003; Marques and Buckland 2004) Here only a short overview is provided to differentiate the estimators.

The fundamental parameter of interest is the density of animals, or the number of animals (*n*) within the surveyed area (*a*). In strip transect sampling, if strips of width 2*w* (one at each side of the strip transect of half-width *w*) and a total line of length L is surveyed, an area of size *a* = 2*w*L is censused and all animals within this area are enumerated. In line transect distance sampling, only a portion of the animals within the surveyed area (*a*) are detected. This unknown proportion of detections is denominated *Pa* and it is estimated as a function of the detection distances data only (CDS), or of distances and covariates (MCDS). In CDS, *Pa* depends only on the distribution of the perpendicular distances (*g*(*x*)), while in MCDS, $\widehat{P}a(\underline{z}_i)$ is the probability that the object *i* is detected, given that it is within the strip of half-width *w*, and given the values of the covariates z_i that can influence the detection.

In CDS *Pa* is estimated as follows:

$$\widehat{P}a = \frac{\int_0^w g(x)dx}{w}$$

And in MCDS, as:

$$\widehat{P}a(\underline{z}_i) = \frac{1}{w}\int g(x,\underline{z}_i)dx = \frac{1}{w}\frac{1}{f(0|\underline{z}_i)}$$

Once $\widehat{P}a$ is estimated the density $\widehat{D}$ is derived as follows:

$$\hat{D} = \frac{n}{2wL\hat{P}a}$$

And in MCDS, as:

$$\hat{D} = \frac{n}{2wL\hat{P}a(\underline{z}i)}$$

And thus abundance with the CDS engine is estimated as:

$$\hat{N} = 4\hat{D} = 4\frac{n\hat{E}[\,]\hat{f}(0)}{2L}$$

And with the MCDS engine it is given by:

$$\hat{N} = \frac{A}{2L}\sum_{i=} \hat{f}(0|\underline{z}i)$$

Where:

A is the survey area;

n is the number of sightings recorded 'on effort';

$\hat{f}(0)$ is the estimated probability density function evaluated at zero distance from the transect line;

$\hat{f}(0|\underline{z}_i)$ is the estimated probability density function evaluated at zero distance from the transect line given the associated covariates $(\underline{z}_i = z_{1i},\ldots,z_{qi})$;

$\hat{E}[\,]$ is the estimated mean group size for each species;

s_i is the size of the *i*th detected group for each species;

L is the total transect line length;

$\hat{g}(0)$ is the probability of detection on the transect line;

$\hat{D}$ is the density of individuals

Pooled data (from all years) of each species was used to estimate *Pa* and the effective strip width (ESW). ESW is the perpendicular distance from the line where all objects are effectively detected, in other words, the number seen at distances beyond ESW equals the number missed at distances less than ESW. $\hat{g}(0)$ (the probability of detection on the transect line) was assumed to be 1.

2.2.7 Annual density and abundance estimates

For management purposes, it is essential to have estimates at short time intervals. In order to have annual estimates, the probability of detection obtained with the whole data set was used as a multiplier. It was assumed here that detection probability do not vary among the years. The adoption of the multiplier allows reliable estimates for all years and all species despite the lower number of detections. A uniform function with no adjustment terms was set in the DISTANCE 6.0 ® (Thomas *et al.* 2010) software and variance was estimated empirically.

2.3 Results

Eighty-seven surveys (Figure 10) covering a total of 4723.86 km were conducted during the summer months from 2006 to 2009 (Table 2). Some of the planned surveys were not undertaken due to unfavourable meteorological conditions. One survey was excluded from the analysis (08/07/2008) because the only completed leg was conducted with low visibility (visibility 1 - <500 m). All other surveys with at least two completed lines with acceptable conditions (n = 8) were kept in order to improve the detection function fit. Each weekly stratum had an average of 9 (±4) surveyed lines.

A total of 647 groups and 850 baleen whale individuals were recorded (Table 3). Observations not classified to the species level (Bsp, n=20) were not used in further analysis. Most sightings of minke, fin and humpback whales were recorded within the SSLMP, while blue whales were recorded at the limit between the down-stream portion of the SSLMP and part of the SLEMPA (Figure 11).

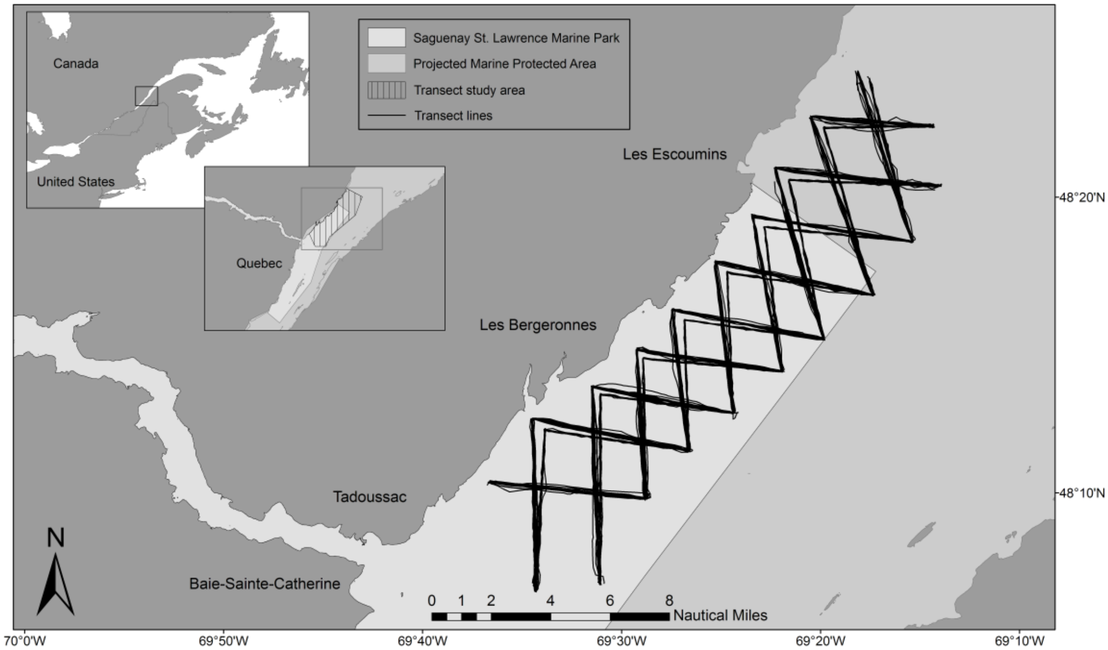


Figure 10. Transect lines completed during four years of systematic surveys conducted within the marine portion of the St. Lawrence River Estuary.

Table 2. Total survey effort in number of days and kilometres for each year.

Year	Effort (days)	Effort (km)
2006	24	1250.83
2007	24	1413.62
2008	19	1034.29
2009	20	1025.12
Total	**87**	**4723.86**

Table 3. Number of groups and of individuals registered by species and year during the systematic surveys conducted at the marine portion of the St. Lawrence River Estuary. (Bsp: Baleen whale non identified to the species level)

Species	**Year**	**Groups**	**Individuals**
Minke	2006	112	119
	2007	130	131
	2008	37	37
	2009	71	71
	Total	**350**	**358**
Fin	2006	72	169
	2007	85	165
	2008	24	31
	2009	20	21
	Total	**201**	**386**
Blue	2006	18	18
	2007	10	11
	2008	3	3
	2009	15	16
	Total	**46**	**48**
Humpback	2006	12	16
	2007	9	12
	2008	2	2
	2009	7	7
	Total	**30**	**37**
Bsp	2006	14	15
	2007	3	3
	2008	1	1
	2009	2	2
	Total	**20**	**21**
Total		**647**	**850**

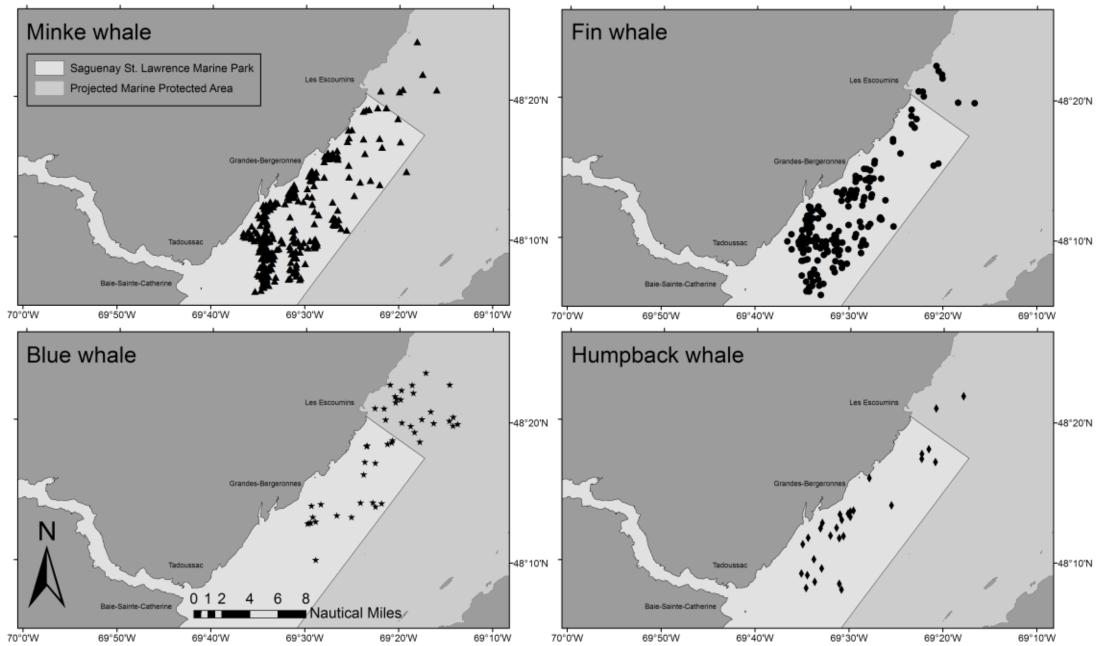


Figure 11. Location of the baleen whales recorded during the four years of systematic surveys conducted at the marine portion of the St. Lawrence River Estuary.

2.3.1 Conventional Distance Sampling

The conventional distance sampling (CDS) engine of the DISTANCE software was preferred to model blue and humpback whales' detection curves due to the low number of sightings ($n<50$) recorded along the four years of survey. Results of model fitting and global abundance estimates are presented below.

2.3.1.1 Blue whales

A total of 46 groups of blue whales were recorded. Blue whales were distributed from Les Bergeronnes and down-stream. Perpendicular distance data were grouped in five intervals (0, 300, 600, 1200, and 2000 m) and right truncation of far sightings was not necessary. Perpendicular distances were best modelled by the half normal function with hermite adjustments based on AIC (

Figure 12). Mean group size was of 1.04 (se=0.0225) individuals and the Chi-square Goodness of Fit test (GOF, *p*=0.48489) supported the adequacy of the detection function model. Overall density of blue whales across the study area was 0.0054 whales/km^2 and average abundance through the study period was of 3 individuals (95% CI= 2-5) (Table 7).

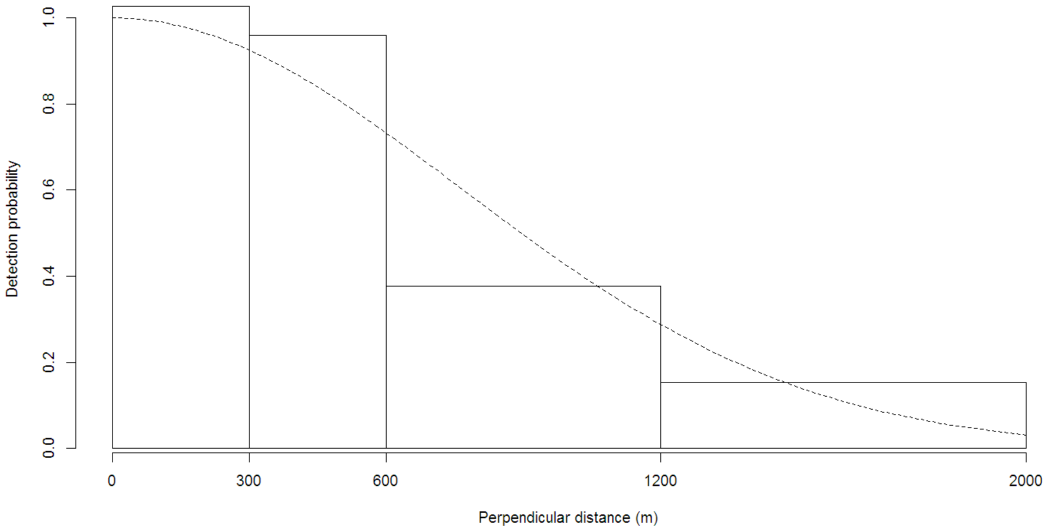


Figure 12. Histogram of recorded perpendicular distances of blue whales from the transect line and fitted detection curve (note that the *x* intervals are not equal).

2.3.1.2 Humpback whales

A total of thirty sightings of humpback whales were recorded on effort (Table 3). Recorded animals were mainly distributed within the SSLMP limits (Figure 11). Perpendicular distance data were grouped in five intervals (0, 400, 900, 1400, and 2000 m) and right truncation was not applied. Perpendicular distance was best modelled by the half normal function with simple polynomial adjustments based on AIC (Figure 13**).** Average group size was of 1.23 (se=0.0785). The Chi-square Goodness of fit test (GOF, *p*=0.56653) was significant, supporting the adequacy of the detection model. Overall density of humpback whales across the study area was 0.0035 whales/km^2 and the average abundance through the study period was 2 individuals (95% CI=1-4) (Table 7).

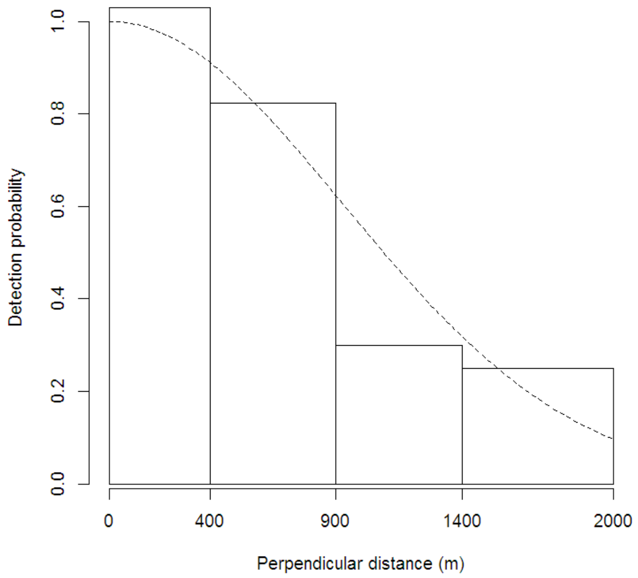


Figure 13. Histogram of recorded perpendicular distances of humpback whales from the transect line and fitted detection curve (note that the *x* intervals are not equal).

2.3.2 Multi-covariate Distance Sampling

A comparison between CDS and Multi-covariate Distance Sampling (MCDS) was performed with minke and fin whale data in order to verify if the inclusion of covariates known to affect the detection improved the detection model fit for these species. Among the four variables collected during the surveys that could affect detection probability, three were retained for further analysis: *observer*, *wave height* and *cloud cover* (Figure 14, Figure 15). As 94.4 % of the surveys took place with *visibility* level 4, *visibility* was not considered as a factor to adjust whales' detection probability. *Observer* one and two had similar numbers of recordings, while observer three was responsible for 5.7% (n=19) and 13% (n= 25) of the total number of sightings (after truncation) of minke and fin whales, respectively. *Wave height* was initially classified into five categories. Level five was never observed and level four was registered only on a few occasions. Level three and four were then merged, and thus three levels were considered to verify the effect of *wave height* in detection probability: 1) mirror; 2) <15 cm and 3) >15 cm. The four levels of *cloud cover* were kept for analysis.

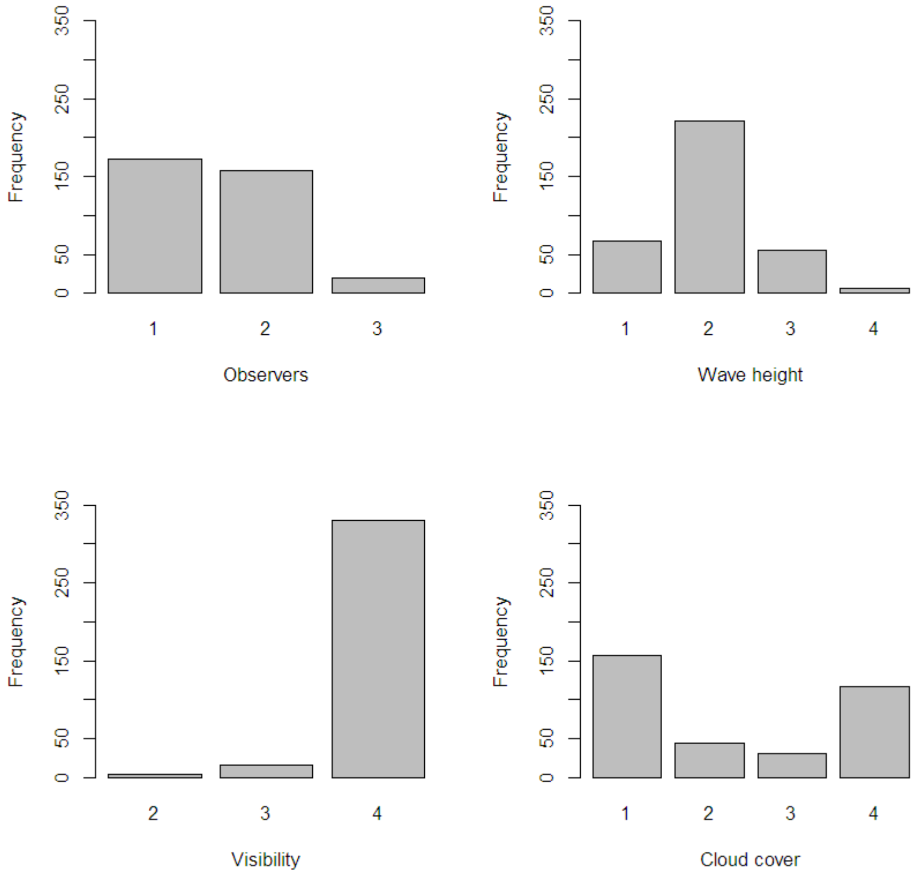


Figure 14. Distribution of variables available to model minke whales' detection function.

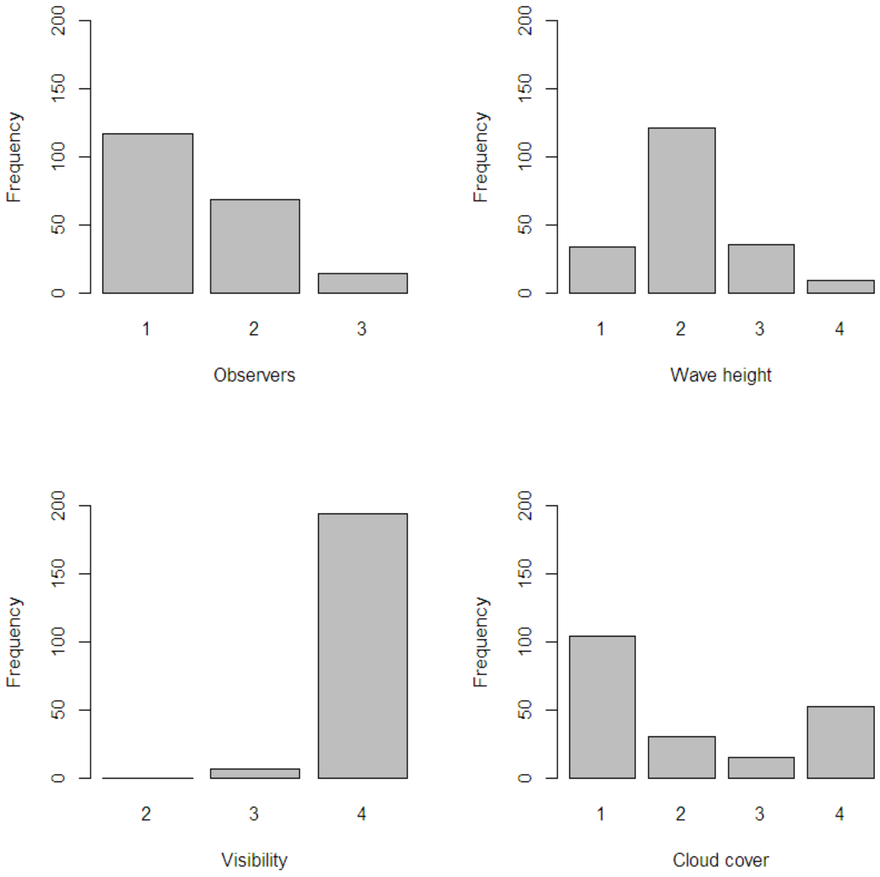


Figure 15. Distribution of variables available to model fin whales' detection function.

2.3.2.1 Minke whales

A total of 350 sightings of minke whales were recorded during the four years of survey (Table 3). Recorded groups were mainly distributed within the SSLMP limits (Figure 11). Truncation was applied to 5% of the data from the right-hand tail of the detection function (Buckland *et al.* 2001). After truncation 335 sightings were available to model the detection function (Figure 16). Perpendicular distances were grouped into 6 classes with break points at 0, 200, 400, 700, 1000, and 1400 m. By using the CDS engine, minke whales perpendicular distance data was best modelled by the half normal function with simple polynomial adjustments based on AIC. Average group size was 1.02 (se: 0.0093) individuals and the Chi-square Goodness of fit test (GOF, *p*= 0.88) supported the adequacy of the detection function model.

The model with no covariates (CDS model) was compared with models derived from the MCDS engine. A stepwise procedure was applied to incorporate the covariates that could affect detection probability (Figure 14). The model with no covariates was chosen based on AIC (Table 4). Estimates of density and abundance of minke whales reported in Table 7 were derived from the model with the lowest AIC (CDS model). Overall density of minke whales across the study area was 0.0775 whales/km^2 and average abundance through the study period was 45 individuals (95% CI= 34-59).

Table 4. Summary of model selection and parameter estimates for models proposed to fit perpendicular distance data for minke whales (#: number of parameters; AIC: Akaike Information Criterion; p: average detection probability; ESW: effective strip width).

Model	#	ΔAIC	AIC	p	p CV	p df	ESW
CDS	3	0.00	956.64	0.33	0.06	332.00	468.52
Observer Wave	5	2.99	959.74	0.41	0.04	330.00	578.52
Observer Wave Cloud	8	5.81	962.82	0.41	0.04	327.00	574.39
Wave	4	7.71	964.36	0.34	0.05	331	472.39
Observer	3	7.94	964.58	0.42	0.04	332.00	589.08
Observer Cloud	4	12.82	969.51	0.42	0.04	331.00	592.29

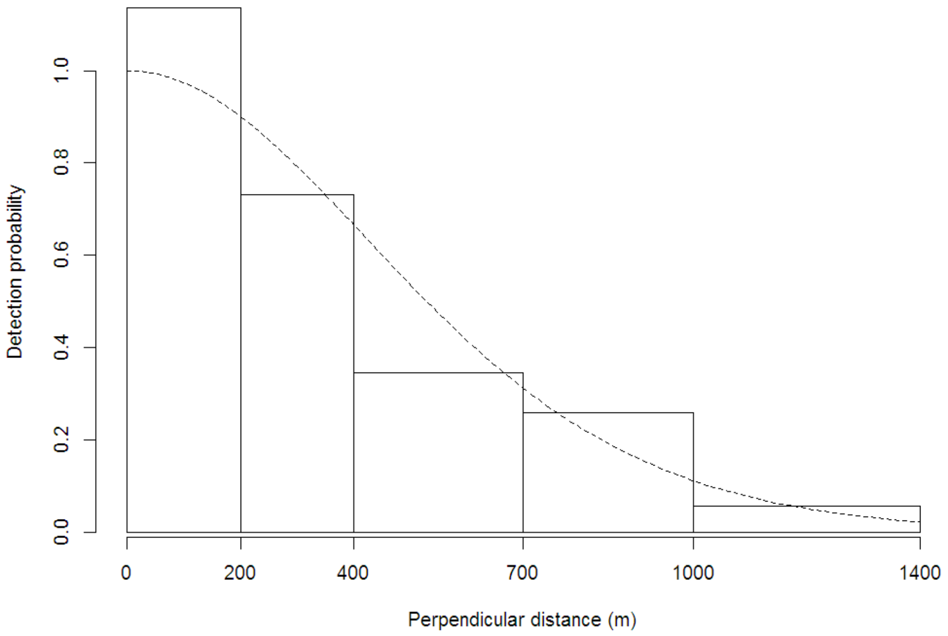


Figure 16. Histogram of recorded perpendicular distances of minke whales from the transect line and fitted detection curve (note that the *x* intervals are not equal).

2.3.2.2 Fin whales

A total of 201 sightings of fin whales were recorded from 2006 to 2009 (Table 3). Most sightings of the species were inside the SSLMP limits. Truncation of 5% was applied to the data, eliminating nine observations whose perpendicular distances were greater than 1600 m. After truncation, 192 sightings were available to fit the detection function. Perpendicular distances were grouped into 6 classes with break points at 200, 400, 600, 800, 1200 and 1600 m. By using the CDS engine, fin whale's perpendicular distance data was best modelled by the half normal function with cosine adjustments based on AIC. Average group size was of 1.8 (se: 0.114) individuals and the Chi-square Goodness of fit test (GOF, *p*=0.7) supported the adequacy of the detection function model.

The model with no covariates (CDS model) was compared with models derived from the MCDS engine. A stepwise procedure was applied to incorporate the variables (Figure 15) that could affect detection probability. The model that considered the effect of wave height and observer and the one with only wave height presented similar values of AIC, both < 2. Estimates of density and abundance of fin whales (Table 7) were derived from the model with the lowest AIC (wave height and observers) (Table 5).The effect of the covariates retained in the analysis is illustrated in Figure 17. With low wave height (level 1 and 2) the observations were closer to the transect line while with wave height 3, the sightings presented a larger range of distances in relation to the transect line (Figure 18, Table 6). Overall density of fin whales across the study area was 0.042 whales/km^2 and average abundance through the study period was 24 individuals (95%CI=18-34).

Table 5. Summary of model selection and parameter estimates for models proposed to fit perpendicular distance data for fin whales (#: number of parameters; AIC: Akaike Information Criterion; p: average detection probability; ESW: effective strip width).

Model	**#**	**Δ AIC**	**AIC**	**p**	**p CV**	**p df**	**ESW**
Wave Observer	5	0.00	672.35	0.56	0.05	187	893.75
Wave	3	0.04	672.52	0.56	0.05	189	902.33
CDS	1	2.31	674.66	0.57	0.06	191	916.22
Observer	3	2.39	674.74	0.57	0.05	189	906.44
Observer Cloud	2	2.65	675.00	0.57	0.05	190	912.38
Observer Wave Observer Cloud	8	4.68	677.03	0.56	0.05	184	888.27
Observer Wave Cloud	6	4.87	677.22	0.56	0.05	186	897.18

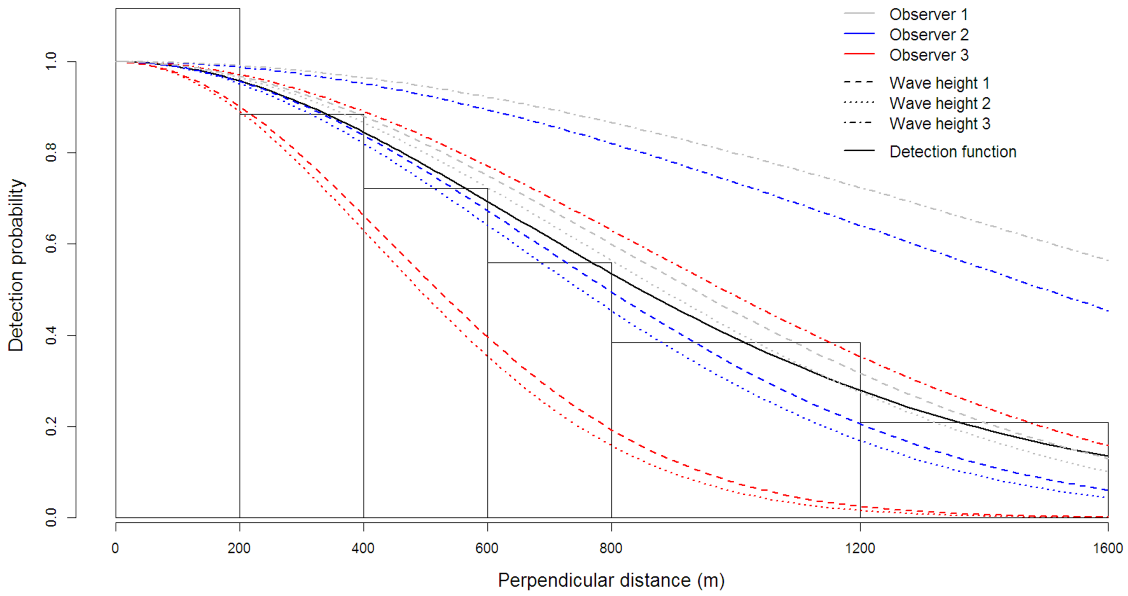


Figure 17. Histogram of perpendicular distances of fin whales from the transect line, fitted detection curve (solid black line) and detection curves for each combination of wave height (dashed, dotted, and dot-dashed) and observer (gray, blue, red) (note that the *x* intervals are not equal).

Table 6. Parameter estimates for the model that best fit fin whale perpendicular distance data.

Model	θ	SE
Intercept	1273	68.51
Wave height level 1	-0.6355	0.4006
Wave height level 2	-0.6935	0.3781
Observer level 3	-0.4251	0.3131
Observer level 1	0.1600	0.1680

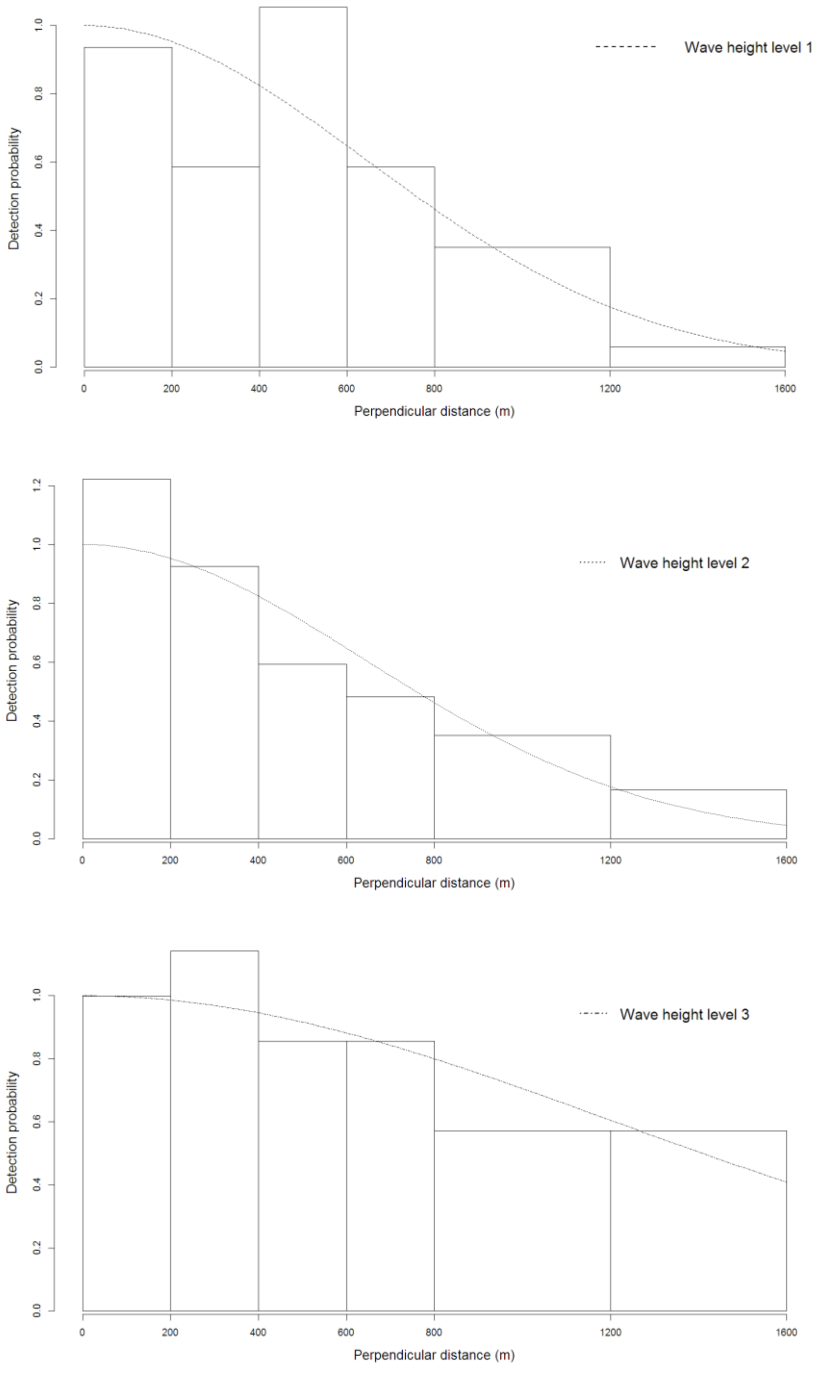


Figure 18. Histogram of perpendicular distances of fin whales observed by wave height level and corresponding fitted detection curve (note that the *x* intervals are not equal).

Table 7. Density and abundance estimates of baleen whales at the marine portion of the St. Lawrence River Estuary (f(0): probability density function at zero distance; p: detection probability; ESW: effective strip width; DS: density of groups (number of groups km^{-2}); D: density of whales (number of whales km^{-2}); N: abundance estimate).

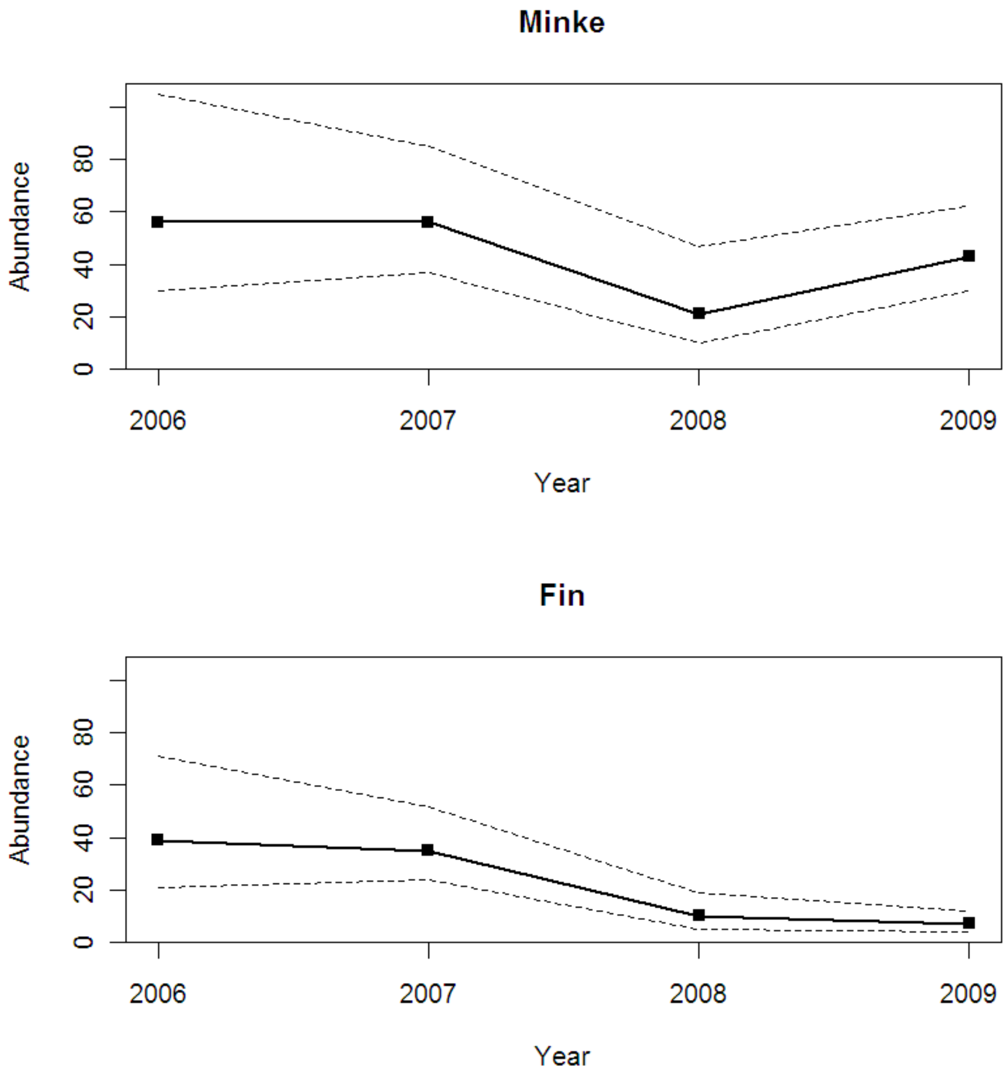
Species	Parameter	Estimate	% CV	df	95% CI	
Minke	**f(0)**	0.0021	5.95	332	0.0019	0.0024
	p	0.3346	5.95	332	0.298	0.376
	ESW	468.52	5.95	332	416.83	526.63
	DS	0.0757	14.09	79.37	0.0572	0.100
	D	0.0775	14.12	80.04	0.0586	0.1025
	N	**45**	14.12	80.04	**34**	**59**
Fin	**f(0)**	0.0011	5.21	187	0.0010	0.0012
	p	0.558	5.21	187	0.504	0.62
	ESW	893.75	5.21	187	806.5	990.44
	DS	0.023	14.98	114.89	0.017	0.03
	D	0.042	16.20	154.45	0.03	0.058
	N	**24**	16.20	154.45	**18**	**34**
Blue	**f(0)**	0.0011	12.30	45	0.00083	0.0014
	p	0.472	12.30	45	0.369	0.605
	ESW	944.99	12.30	45	738.37	1209.4
	DS	0.0051	24.52	84.87	0.0032	0.0083
	D	0.0054	24.70	87.25	0.0033	0.0087
	N	**3**	24.70	87.25	**2**	**5**
Humpback	**f(0)**	0.00089	15.89	29	0.00064	0.0012
	p	0.562	15.89	29	0.407	0.776
	ESW	1123.4	15.89	29	813.33	1551.8
	DS	0.0028	27.50	82.91	0.00165	0.0048
	D	0.0035	28.23	91.3	0.0020	0.0060
	N	**2**	28.23	91.3	**1**	**4**

2.3.3 Annual density and abundance

Annual density and abundance of each baleen whale species is presented in Table 8. Abundance of all baleen whale species was lower in 2008, the year with the higher coefficient of variation for all species. The abundance of minke whales reached a minimum in 2008 (Figure 19), and returned to 2006-2007 levels in 2009. The abundance of fin whales during the study period showed a progressive decline from 2006 up to 2009 (Figure 19) while the abundance of blue whales showed an opposite tendency, with an increasing abundance within the period (Figure 20). The abundance of humpback whales was almost constant along the period, with the exception of 2008 (Figure 20).

Table 8. Annual density and abundance estimates of baleen whales at the marine portion of the St. Lawrence River Estuary (D: density of whales (number of whales km^{-2}); N: abundance estimate).

Species	**Year**	**D**	**N**	**% CV**	**N 95% CI**	***df***
Minke	**2006**	0.097	56	29.5	30 - 105	13
	2007	0.096	56	20.0	37 - 85	15
	2008	0.037	21	37.6	10 - 47	11
	2009	0.074	43	17.2	30 - 62	12
Fin	**2006**	0.067	39	28.9	21 - 71	17
	2007	0.061	35	19.1	24 - 52	25
	2008	0.017	10	32.6	5 - 19	16
	2009	0.011	7	26.0	4 - 12	13
Blue	**2006**	0.008	4	27.2	2 - 8	13
	2007	0.004	2	39.0	1 - 5	17
	2008	0.002	1	59.7	0 - 3	11
	2009	0.008	5	50.1	2 - 13	12
Humpback	**2006**	0.006	3	39.0	1 - 7	16
	2007	0.004	2	36.0	1 - 5	20
	2008	0.001	0	84.0	0 - 3	11
	2009	0.003	2	62.0	1 - 6	12



Minke

Fin

Figure 19. Annual abundance estimate of minke and fin whales (2006 to 2009) occurring within the marine portion of the St. Lawrence River Estuary.

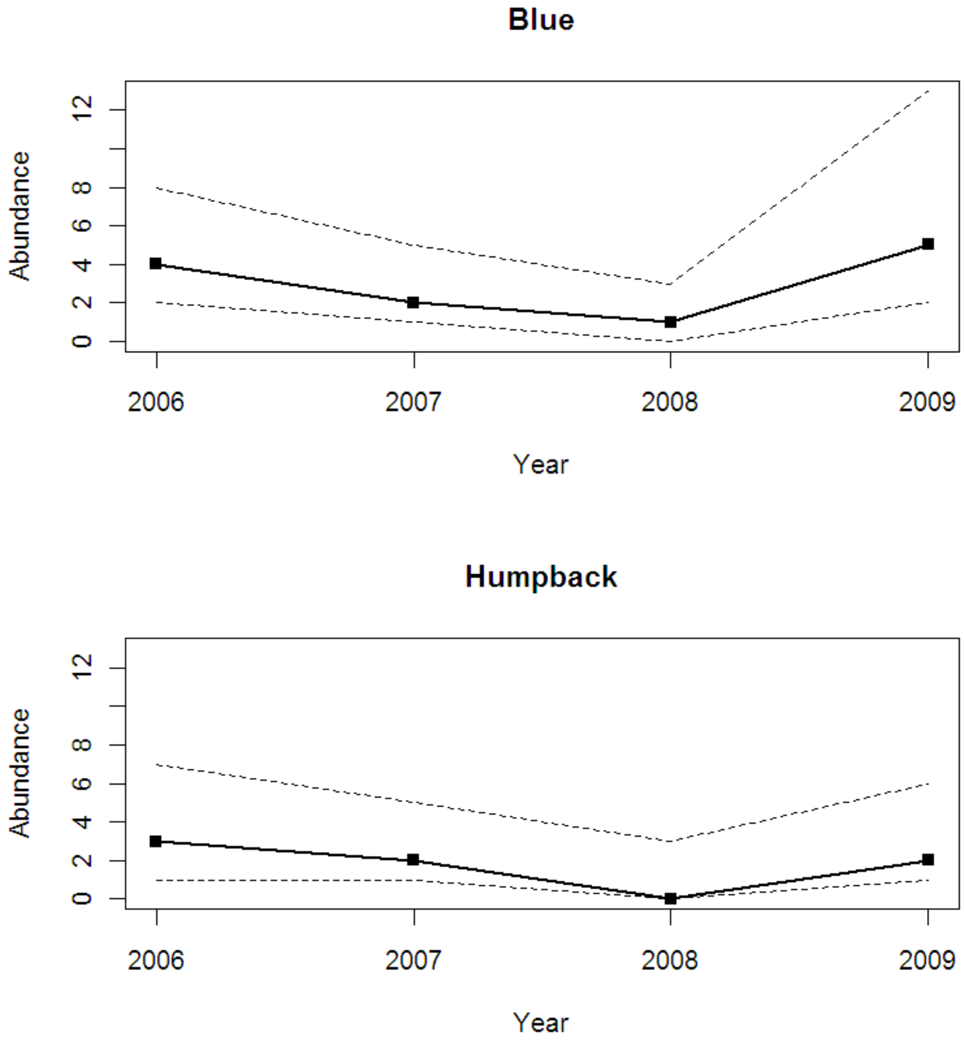


Figure 20. Annual abundance estimate of blue and humpback whales (2006 to 2009) occurring within the marine portion of the St. Lawrence River Estuary.

2.4 Discussion

The results presented here were part of the first systematic effort to estimate density and abundance of baleen whales in the study area using boat-based line transect distance sampling. The project was an initiative of the GREMM, and was supported by Parks Canada and the DFO. The study covered almost five thousand kilometres of effort over the four years, and the high number of repetitions of the survey was the key for the robustness of the estimates.

Knowledge of baleen whales' abundance and distribution is essential for conservation and management purposes. It is part of the basic information needed to gain a better understanding of the species' ecology and of their management needs. Line transect distance sampling is the most prevalent systematic method to acquire data on species distribution, while at the same time allowing for estimates of density and abundance (Hiby and Hammond 1989; Buckland *et al.* 2001). The results presented here provide the first reliable density and abundance estimates for the four species of baleen whales, essential information for management purposes and that was previously lacking. In addition, it indicates the possible presence of cyclical fluctuations highlighting the need for long-term surveys in order to monitor population trends.

2.4.1 Density and abundance estimates

During the surveyed period minke whales were the most abundant species in the study area, followed by fin whales. Blue and humpback whales were present in very low numbers, and were here denominated as rare species.

2.4.1.1 CDS versus MCDS

The CDS was the only engine used to run the analysis for the rare species due to the low number of records. However, even if the sample size was reduced, the detection function fit and the produced estimates were robust. The MCDS model which included *observer* and *wave height* as covariates to model minke whales' perpendicular distances presented a higher detection probability with a smaller coefficient of variation (p=0.41, CV=0.04) when compared to the CDS model. However, due to the higher number of parameters (five instead of three), the CDS model was favoured by the AIC.

The same variables were retained to improve the detection function fit of fin whales.

Wave height had a direct effect on the model fit and its effect is well illustrated in Figure 18. In the presence of waves (>16 cm) the detection probability tended to be more uniform along the distance categories. *Observer* variability was also incorporated by the chosen model, but was not as important as *wave height*. The model which included only *wave height* presented an AIC very close to zero. The inclusion of the covariates improved the estimates but the effect of the *wave height* itself should be interpreted with caution.

As fin whales are a large cetacean species that can be easily observed from a distance, it is counter-intuitive to think that waves higher than 16 cm would have an effect on detection of the species. Instead, this result might indicate that observers' attention varied depending on the waves' height, *i.e.* in the presence of waves the attention was deviated from the transect line. Another possibility is that distance measures, which were visually estimated, were affected by wave height. With small cetacean species the contrary is usually observed, as wave height increases, detection is more efficient closer to the transect line (Jefferson and Leatherwood 1997). Here, this pattern was observed with the minke whales data, although its effect was not strong enough to be retained after model selection.

Although the MCDS model was favoured for the fin whales' data, the detection probability was very similar with and without the covariates. A possible explanation for the small difference is the relatively homogeneous sighting conditions throughout the study and/or that the covariates selected do not affect the ability to detect these species (Zerbini *et al.* 2006).

2.4.1.2 Annual density and abundance estimates

Annual estimates give another portrait of the baleen whales density and abundance in the study area. 2008 was a very peculiar year, with a very low abundance for all species, in particular for the most abundant species. The observed decline for fin whales seems to be concomitant to an increase in blue whales abundance. This result highlights the importance of long-term data collection for the understanding of cetacean population dynamics.

Cyclical fluctuations of long living animal species abundance in an area are usually linked to the availability of prey. It was observed that the abundance of minke and humpback whales in Antarctic waters varied with time and was related to the extent and nature of sea-ice cover, which in turn govern the population dynamics of krill (Thiele *et al.* 2004). Krill biomass fluctuations are known to occur in the area, but the pattern is still to be understood (I. McQuinn, personal communication). In 2009, the SSLMP began a long-term monitoring of the prey species within the marine portion of the park. This study may bring important insights on the system functioning and how the whales' abundances are related to prey availability.

2.4.2 Line transect distance sampling assumptions

As stated in the methods section, the accuracy of the distance sampling method relies on three main assumptions (Buckland *et al.* 2001). The first assumption states that animals on the transect line are detected with certainty, or that g(0)=1. For cetacean species, which spend most of their time underneath the water surface, failure to meet this assumption is common and causes negative biases in density estimates (Buckland *et al.* 2001). The proportion of animals lost on the transect line could be estimated by conducting a mark recapture survey (Buckland *et al.* 2001; Thomas *et al.* 2010) in which two observers would record independently the animals on the transect line. Known estimates of g(0) for large whales due to perception bias range from 0.9 -1 (Barlow 1995; Williams *et al.* 2006). In the present study, minke whales are the only species whose g(0) might be different from one due to the species' characteristics (i.e. smaller size, absence of visible blow). By assuming g(0)=1 the minke whale abundance estimates presented here represent a conservative estimate of the target species. A study conducted in the North Atlantic estimated that 56-68% of minke whales were missed (Skaug and Schweder 1999) and for Antarctic minke whales a g(0) of 0.9 was estimated (Williams *et al.* 2006).

Here, two factors might have influenced g(0): the single observer and the high boat speed. The method is usually applied with at least two observers, each scanning a different side of the transect line and doubling the effort on the transect line. In addition, boat speed has a direct effect on animal availability (i.e. the time an animal is within the visual range of an observer), a factor that can be easily estimated to produce a correction factor (Barlow 1988). This approach was used to correct aerial survey estimates of humpback whales in Brazil (Andriolo *et al.* 2006).

The second assumption states that objects are detected at their initial location, or that no movement towards or against the survey platform is observed. Movement prior to detection biases the estimator of density negatively or positively, if animals avoid or approach the survey platform respectively (Buckland *et al.* 2001). Ideally, it can be avoided if the observer looks well ahead as the area is searched and records any sighting at its initial position. In general, responsive behaviour is an issue for small dolphins (Barlow 1995; Williams and Thomas 2007). A careful inspection of the perpendicular distance histograms (ungrouped data) can indicate the presence of evasive movement prior to detection (greater frequencies beyond zero distance). For all baleen whale species the detection function presented a shoulder, and even for the rare species, to which the primary issue was of small sample size, movement prior detection does not seem to be a problem.

Measurement accuracy is the third assumption. The angle and the distance to the recorded whale must be as accurate as possible. In the present study, angles were recorded with a hand held electronic compass, but distances were estimated visually (‘eyeballing’). Even if observers often calibrated their estimates with the boat radar, it is known that observers tend to round to convenient values despite the use of measurement instruments (Buckland *et al.* 2001). The effect of inaccurate measurements can often be reduced by grouping the perpendicular distances. Here, they were grouped after a careful analysis of ungrouped data histograms. As recommended, break points were chosen in order to force the heaped values (most frequent values) to fall approximately at the mid points of the groups (Buckland *et al.* 2001). In addition, bands with increasing intervals were preferred (Andriolo *et al.* 2005) as a solution to accommodate the effect of the low height of the survey platform (which might affect measurement accuracy at greater distances).

The height of the survey platform also has a direct effect on the detection range, which in its turn will vary depending on the species' behaviour. Zerbini (2006) reported mean radial distances of detected fin and humpback whales of 2.72 and 2.66 km, and of 1.3 km for minke whales from survey platforms at least 10 m above the sea level. Here, for all baleen whale species, the effective strip width was smaller than 1 km, and for minke whales was smaller than 500 m, a clear effect of the survey platform height. Ship surveys (with heights of around 10 m above the sea level) for large whales usually result in a higher ESW (Clapham *et al.* 2003; Zerbini *et al.* 2004; Andriolo *et al.* 2010), although for minke whales ESW are usually of the same order (Skaug *et al.* 2004) due to the species behaviour.

Another important assumption is that observations are independent, an assumption that is respected with a proper sampling design (Buckland *et al.* 2001; Thomas *et al.* 2007; Dawson *et al.* 2008). The transect lines must be placed at random within the surveyed area to allow equal coverage probability (Buckland *et al.* 2001). The study was formally designed to evaluate the intra-seasonal variation of density and abundance within the area in which the WW industry concentrates its activities. It forced the transect lines to be within the submarine canyon limits and followed a zigzag design to optimize time on effort.

The apexes of zigzags present potential problems (Dawson *et al.* 2008). In addition to the chance of double counting the same animal in two consecutive lines, having recently made a sighting near the apex, the observer might subconsciously bias his/her sighting effort at the beginning of the next leg (Dawson *et al.* 2008). The number of minke whale sightings at the apexes was elevated mainly in zones close to the northern shore coastline where submarine cliffs are present. However, it is known that the species tends to feed near the submarine cliffs, justifying the higher proportion of sightings (decreasing the possibility of double counting) but not the bias of sighting effort.

2.4.3 Recommendations

After the pre-analysis of the data from 2006 to 2008, a parallel design was suggested to reduce the effect of the apexes. Also, the southern limit of the lines was extended to include the area beyond the cliff limit. The new design (Figure 21) was followed by the

GREMM in 2010 and 2011. However, boat speed was maintained and the number of completed lines per survey was kept low (5 lines within the park for each repetition of the survey) to fit within the same study area limits.

In order to have robust variance estimates the method requires 10 to 20 lines per survey (Buckland *et al.* 2001). As the detection function of all species was fitted to the pooled data (from 2006 to 2009) good variance estimates were obtained for the global and annual estimates. But for shorter periods of time, the estimates would present unacceptable variability. Data was organised in weeks to improve this aspect, and each resulted stratum had 9 (±4) surveyed lines. Other data organization formats (e.g. combinations of three surveys with different start points) would also be possible, but probably with other methodological constraints (e.g. immigration and emigration as it would force the stratum to cover a wider period). The best solution to guarantee estimates with low variability for shorter periods of time would be to run a joint analysis with the data collected by Gosselin and colleagues. The latter conducted line transect distance surveys from the downstream limit of the present study area up to Cap Colombier (J.-F. Gosselin, personal communication), almost at the limit of the proposed St. Lawrence Estuary Marine Protected Area (SLEMPA).

As a management instrument, up to three surveys per year encompassing the marine portion of both MPAs, the SSLMP and the SLEMPA, would provide stakeholders with enough data to follow all marine mammal species' population trends. By surveying a larger area at the same time it would ensure an adequate number of completed lines, and a better overview of the animals' distribution within the MPAs. Due to the logistic constraints of such a survey, it could be repeated once a year at the peak of the feeding season (early August) covering the whole area and twice in the most dense areas (before and after the complete survey). A draft of a possible design is presented in Figure 22 only as an indication of the ideal study area (*i.e.* at the best the lines would be adjusted into different spatial strata, avoiding the longer lines; along with an adequate evaluation of the coverage probability). Also, two observers and a reduced speed (8-10 knots) would improve the estimates by increasing the time for animals to surface within viewing range (Dawson *et al.* 2008). The only constraint with this design would be a reduced probability of detecting the rare species, as the blue whale.

Due to the characteristics of the study area, it is strongly recommended the comparison of line transect distance sampling abundance estimates with estimates derived from mark-recapture studies of photo-identified animals. With a good survey design, photo-identification data provides reliable abundance estimates besides highlighting many other aspects of the ecology of the target species (*i.e.* residency pattern, association pattern). However, photo-identification data treatment and analysis are part of a long process while line transect distance sampling provides more rapid results, and are thus more practical and cost effective to support management actions. In the area, photo-identification studies have been carried out since the late 1970s although with an irregular effort. These data have not yet been used to produce abundance estimates.

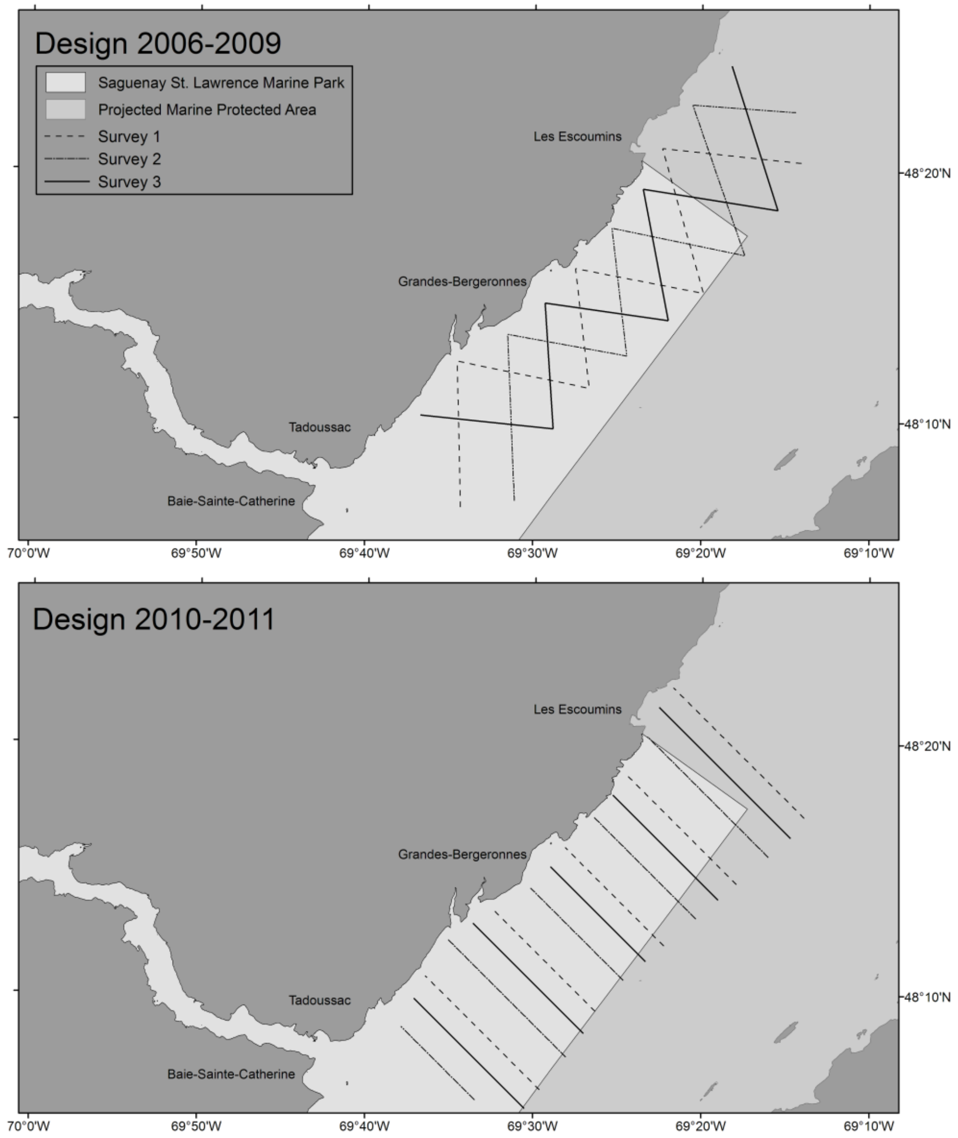


Figure 21. Design used during systematic distance sampling surveys from 2006 to 2009 and the proposed one that was adopted for 2010-2011 to ensure equal coverage probability (each day a different survey design (1, 2 or 3) was realized).

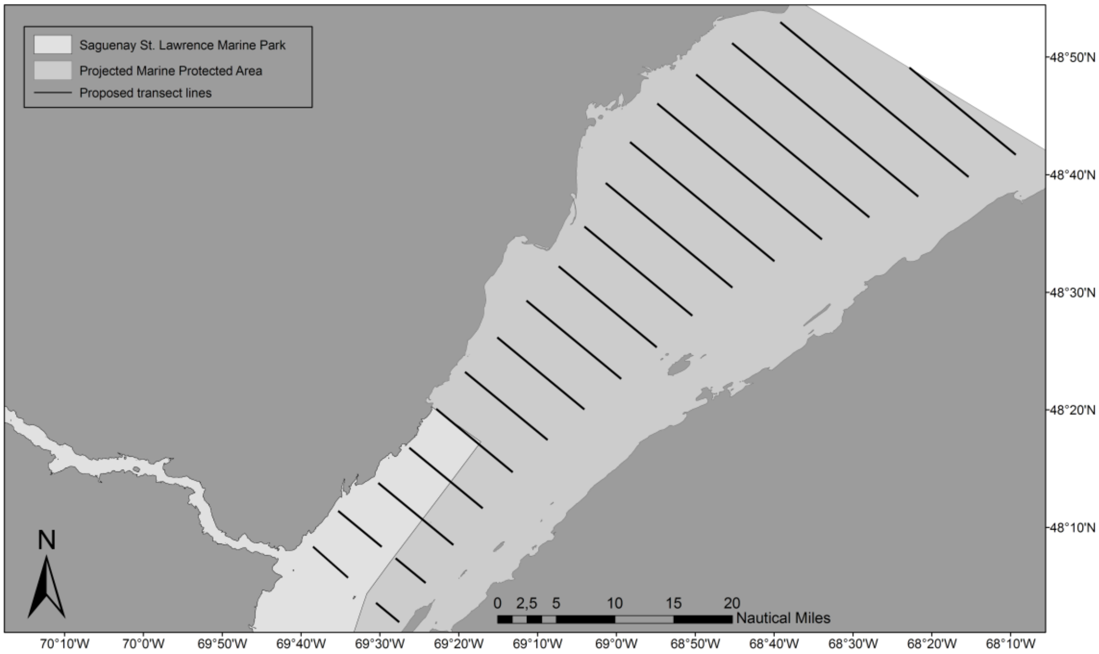


Figure 22. Example of design to estimate cetacean density and abundance while allowing for equal coverage probability covering the whole marine portion of the St. Lawrence River Estuary (restricted to the area within the 40 m isobaths).

2.5 Conclusion

The present analysis involved the use of the data collected initially for another purpose to provide the first estimates of abundance for the four species of baleen whales occurring in the St. Lawrence River Estuary. A detailed analysis of the data collection methods allowed validating its applicability for estimating abundances and highlighting the needs to improve future research.

The estimates produced in the present study provide baseline information on baleen whales density and abundance in the study area, which will allow monitoring these species over time. The present results bring attention to the fragility of this system, which is composed of only a few individuals of each species. It emphasizes the need to enhance management actions to guarantee the maintenance of the system’s integrity and as consequence of the species that depend on it, and of the economic activities that rely on it.

Chapter 3

A spatial density model of baleen whales within the St. Lawrence River Estuary

3.1 Introduction

Line transect distance sampling is the standard method applied for estimating the size of wildlife populations worldwide (Hiby and Hammond 1989; Buckland *et al.* 2001). Increasingly, wildlife managers wish to extract more than just abundance estimates from their sightings surveys (Hedley and Buckland 2004). There is an increasing need to understand the factors governing animals' distributions, and to pass from simple models, to models that allow hypothesis testing (Redfern *et al.* 2006). Besides, there is an urgent need to minimize adverse anthropogenic impacts on wildlife populations (Redfern *et al.* 2006). The later, may not be achieved properly without an appropriate background on how wildlife species use their habitat, and how their distribution is governed by space and environmental factors.

Model-based methods (MBM) are a promising approach to reach this goal. They are based on fitting a model that describes density along the transect line as a function of spatial and environmental covariates. The fitted model is then used to predict density over the whole study area. The model accounts for variability in the data to obtain the best estimate of abundance (Hedley *et al.* 1999; Hammond 2010), in addition to providing the cartography of the density over the study area.

Due to its characteristics, practitioners are moving towards the use of MBM instead of using only designed-based methods (DBM). By DBM we include all methods where the properties of the survey design are used to make inferences about a population, as it was presented in the previous chapter. By consequence, the quality and precision of the inferences are dependent upon an appropriate design, in which the transect lines are placed at random and each part of the study area has an equal probability of being surveyed (Buckland *et al.* 2001; Thomas *et al.* 2007). By using MBM, the assumption of random placement of transect lines is relaxed because abundance is estimated via a model relating density to spatial and environmental variables. MBM are much more flexible and even though it is desirable to have a set of transect lines with sufficient spatial spread to provide representative coverage of the survey area (Hedley and Buckland 2004), they have been successfully applied to platforms of opportunity data, in which the survey design is not pre-determined (e.g. whale watching boats, cruise ships, fishing boats) (Canadas *et al.* 2005; De Segura *et al.* 2007; Canadas and Hammond 2008). In addition, MBM offer a potential for more precise abundance estimates to systematic line transect data than DBM (Thomas *et al.* 2007). By modelling the spatial variation in density, they may provide higher precision for abundance estimation in the whole survey area than stratified estimation methods.

The use of MBM or spatial density modelling (SDM - as it will be referred to from now on) of line transect distance sampling data to estimate cetacean abundance was introduced by Hedley *et al.* (1999) and was further expanded in Hedley and Buckland (2004) and Hedley *et al.* (2004). SDM requires more sophisticated analysis methods than DBM (Hedley and Buckland 2004). Although the results are usually improved as part of the variance of the data is explained by the environmental variables (Hedley *et al.* 2004; Ferguson *et al.* 2006; Gomez de Segura *et al.* 2007) resulting estimates may be biased by model mis-specification. The results are extremely dependent upon the adequacy of the built model and of the adopted variables, stressing the importance of model selection and choice of environmental variables.

The choice of environmental variables to build a SDM will depend on the target species main activity within the study area (i.e. breeding or feeding areas). At the best, environmental variables are collected concomitant with cetacean data (e.g. Ferguson *et al.* 2006) but when in situ data are not available, they may be derived from bathymetric data (Moses and Finn 1997; Martins *et al.* 2001; Hooker *et al.* 2002; Garaffo *et al.* 2007), remotely sensed data (Gregr and Trites 2001; Hamazaki 2002; Baumgartner *et al.* 2003; Doniol-Valcroze *et al.* 2007; Gomez de Segura *et al.* 2007; Cotté *et al.* 2008; Panigada *et al.* 2008; Forney *et al.* 2012), prey abundance data (e.g. Friedlaender *et al.* 2006) and models of oceanographic processes (Dalla Rosa *et al.* 2012). Physical oceanographic data typically represent proxies for prey abundance or availability, which are expected to directly influence cetacean distribution (Redfern *et al.* 2006). The choice of variables depends also on the desired spatial resolution for the analysis: *in situ* data allow finer spatial and temporal resolution than satellite-derived data or predictions from oceanographic circulation models (Redfern *et al.* 2006).

Despite all advantages of SDM, they are not guaranteed to be unbiased and it is often desirable to be able to produce design-based and model-based estimates to compare both results (Thomas *et al.* 2007). In the previous Chapter DBM were used to estimate density and abundance of the four baleen whale species that occur within the St. Lawrence River Estuary (SLRE). In the present chapter, the same data set was used to build a SDM for each species. The results were compared with the estimates derived from DBM, and prediction maps within the study area were built. Due to the lack of data outside the Saguenay St. Lawrence Marine Park (SSLMP), and the need to identify the core areas used by blue whales as part of the recovery plan for this species (Beauchamp *et al.* 2009), density beyond the surveyed area was extrapolated and the resulted prediction map was visually compared with independent data sets. The present work improves our knowledge about baleen whales habitat use within the study area and provides support to the management of the SLRE.

3.2 Material and Methods

3.2.1 Data collection, survey area and survey period

Data were collected following a line transect distance sampling protocol within the marine portion of the SLRE (Figure 23). Boat based systematic surveys took place three times a week weather permitting during the feeding season (middle June to late September) from 2006 to 2009. A complete description of data collection is provided in Chapter 2.

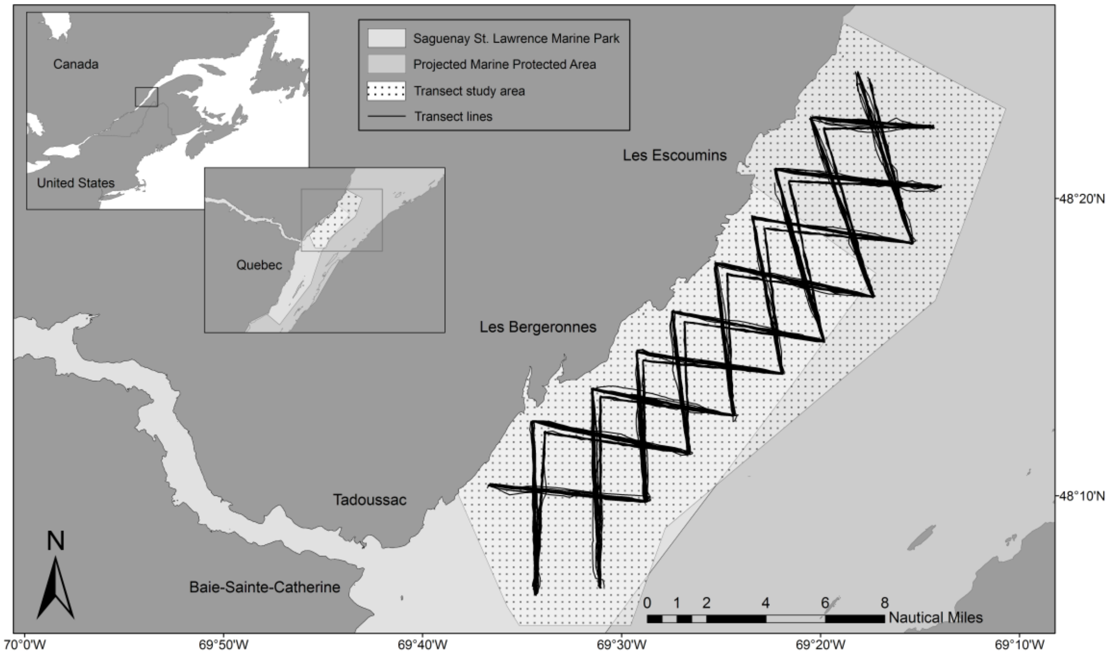


Figure 23. Area covered during line transect distance sampling surveys within the marine portion of the St. Lawrence River Estuary.

3.2.2 Data preparation

The survey effort (kilometres navigated) was recorded using a GPS Garmin Foretrex 301. Each resulting transect of length L was divided into segments *l* of two km (Figure 24). This resolution was chosen in order to ensure that there would be little variability in physical and environmental features within segments and to reduce the number of segments with zero sightings. To deal with irregular transect ends, no segments were allowed to be smaller than one or longer than three km. To each segment l_i a central point was attributed and the baleen whales' observations (number of groups of each species) recorded within the segment were assigned to that point.

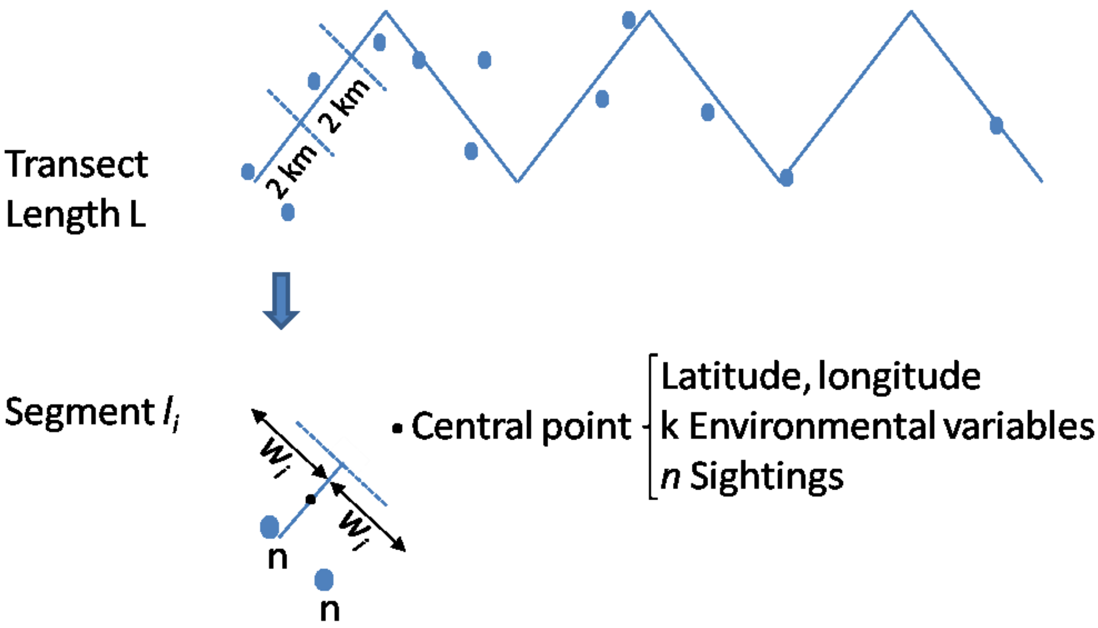


Figure 24. Illustration of notation and of data preparation steps: the transect of length L was subdivided in segments of length *l* (2 km), to which a central point was attributed and geographic coordinates, k environmental variables and the n recorded sightings (number of groups of each species) were associated (*w* is the effective strip width).

Each segment l_i was then characterized by a set of environmental variables (Table 9). Longitude and latitude corresponded to the coordinate of the central point. Water depth and sea floor slope were obtained from a numeric model at a resolution of 100 m. Slope in degrees was obtained with the tool "*Slope*" of *Spatial Analyst* extension of ArcGIS 9.3. Distance to the coast was calculated as the distance between the midpoint and the nearest point at the northern coast, using the tool "*Near*" of the same extension. The mean and standard deviation of depth and slope were calculated using the midpoint of each segment and its entourage within a 1 km radius. A function was created to perform this operation using R 2.10.1 (R Development Core Team 2009). ArcGIS 9.3 and R were used to perform Geographic Information System operations and to map the results.

Data exploration followed the steps delineated by Zurr *et al.* (2009). Correlation among the environmental variables was calculated in R 2.10.1 (R Development Core Team 2009). The R library *AED* (Zuur *et al.* 2007) was used to calculate the variation inflation factor (VIF) index, which indicates the degree of collinearity among the variables. A VIF > 3 indicates high collinearity and precludes the use of such variables in the same model. In addition to the raw variables, logarithmic and square root transformations of slope and depth (mean and SD), respectively, were also used.

Table 9. Definition of the spatial and environmental variables used to model baleen whales' density in the marine portion of the SLRE.

Variable	**Definition**
Longitude	Longitude in UTM NAD 83 Zone 19 N
Latitude	Latitude in UTM NAD 83 Zone 19 N
Depth	Average depth (m)
SD Depth	Standard deviation of depth
Slope	Average of slope (degrees)
SD Slope	Standard deviation of slope
Coastline distance	Nearest distance to the northern shore (m)

3.2.3 The count method

Baleen whales' density was modelled using the count method (Hedley and Buckland 2004). The method considers a strip transect in which transect lines of total length L are covered within a survey area A, and assumes that all animals out to a perpendicular width *w* on either side of the lines are detected with certainty and that any detections made beyond *w* are excluded from the analysis. The total length L of the strip transect is divided into T small contiguous sampling units or segments each of approximately equal length *l*, and the length *l* of each segment is such that the geographic location does not change appreciably within a segment (Figure 24). If the length of the *i*th segment is denoted by l_i, and the number of animals detected within it by n_i, *i*=1, …,T, and if for each segment, a set of k spatial and environmental covariates is available, the expected value of n_i can be modelled as a function of the covariates using a formulation as follows:

$$E(n_i) = \exp\left[\ln(2l_i\ w_i \hat{p}_i) + \beta_0 + \sum_k \beta\ z_{ik} \right]$$

where the logarithm of the area of each segment $\ln(2l_i\ w_i \hat{p}_i)$ enters the linear predictor as an offset, β is the intercept and β , k=0, …, K, are the parameters to be estimated.

3.2.4 Modelling framework

A generalized additive model (GAM) (Hastie and Tibshirani 1990) was used to model the count (n_i) and predict a SDM for each species. The modelling framework followed a six-stage approach (Figure 25): (1) a detection function was fitted from the line transect data for each species; (2) a GAM was fitted to model the count of each whale species in each segment l_i as a function of environmental covariates; (3) the best model was selected; (4) the best model was used to predict whale density throughout the study region; (5) the model was validated by inspecting the presence of spatial autocorrelation in the residuals; and (6) variance was estimated with a nonparametric bootstrap. Below, follows a description of each of the six modelling stages. An annotated version of the R 2.10.1 (R Development Core Team 2009) code is presented in annex 1.

1. **Detection function**

The estimated probability of detection $\hat{p}_i$ was considered to be equal for all segments (i.e. independent of observers, wave height, etc). The values estimated with the software Distance 6.0 ® ((Thomas *et al.* 2010) (Chapter 2), for each species, were adopted here.

2. Model fit

The density of groups was modelled using GAMs. GAMs are semiparametric models where the dependent variable is linked to an additive predictor through a nonlinear link function (Hastie and Tibshirani 1990). GAMs are implemented in the R package *mgcv* and uses penalized regression spline (Wood and Augustin 2002). The use of penalized regression spline ensures a lower computational cost to the model fitting process (Wood and Augustin 2002). The implementation of a quasi-Poisson error distribution, with variance proportional to the mean, was used to account for overdispersion in the data (*i.e.* to account for the high variance of the data). The model was fitted with a logarithmic link function and using the area covered by each segment as an offset as stated above.

The degree of smoothing is determined by the degrees of freedom (*df*) of the model, and the larger the *df* the more flexible the function obtained. A GAM in which the *df* is equal to one is equivalent to a simple linear regression. In *mgcv* the selection of degrees of freedom is an integral part of model fitting (Wood 2001). However, large *df* can result in overfitting. To reduce the chances of overfitting the basis dimension parameter (k) was set to 4. A value of k=4 limits the maximum allowable degrees of freedom of each term to 3 (k-1), avoiding overfitting and restraining the wiliness of the smooth function of the model terms. Within the *mgcv* package, the gamma parameter was fixed at 1.4 (Kim and Gu 2004). This measure is also recommended to avoid overfitting as it inflates the effective degrees of freedom by 1.4 in the GVC score (Wood 2006).

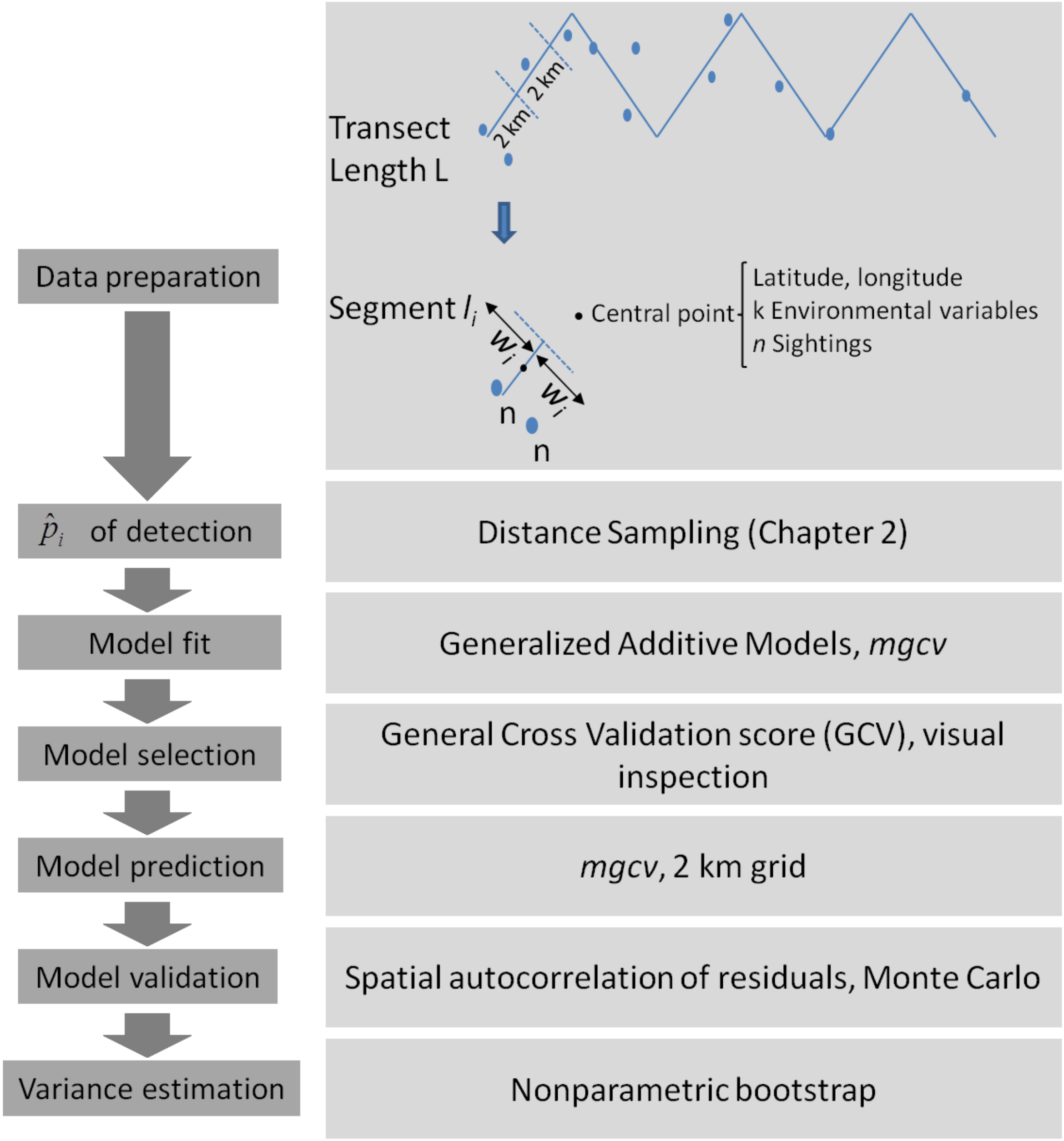


Figure 25. Modeling framework to model the count data and predict the density of each baleen whale species within the study area.

3. Model selection

A backward stepwise manual selection was performed using General Cross Validation score (GCV) (Wood and Augustin 2002). GCV is a criterion similar to the Akaike Information Criterion (AIC), as it allows the comparison of different models to minimise the score. Besides using the GCV, a careful analysis of each term included in the model was performed to verify: 1) if the estimated degrees of freedom were close to one (which indicates a linear relationship); 2) if the smooth function was completely within the zero (i.e. entire confidence limits around zero) and 3) if the GCV for the model decreased if the term was removed from the model. If the answer to all these questions was affirmative, the term was dropped, and if the answer was affirmative only to the first question, the model was tested with this term as a linear predictor (Wood and Augustin 2002). Having dropped all terms that were non significant, model selection was based on the GCV score and on the percentage of deviance explained. If two models had similar GCV, the choice was based on deviance explained and on signals of overfitting.

At first a visual inspection of the residuals with the function *gam.check* of *mgcv* of each tested model was performed to verify the distribution and the normality of the residuals and identify possible patterns. *Depth* and *Slope* were included in the model without transformation and with a squared root and log transformation, respectively. The level of significance to justify the inclusion of a term into the model was 0.05.

4. Model prediction

A grid of 2 km resolution was chosen for prediction. The prediction grid was designed to cover the original systematic survey area (Figure 26) and thus, the prediction only interpolated density between track lines. Marginal grid cells that were not completely within the study area limits (> 75% within) were excluded to minimise edge effects.

A geographic coordinate (latitude and longitude) was attributed to the midpoint of each grid cell. Mean and the standard deviation of depth and slope were calculated using the midpoint of each grid cell and its entourage of one km radius using Spatial Analyst tools (ArcGIS 9.3). Distance to the coast was calculated as the distance between the midpoint and the nearest point at the northern coast.

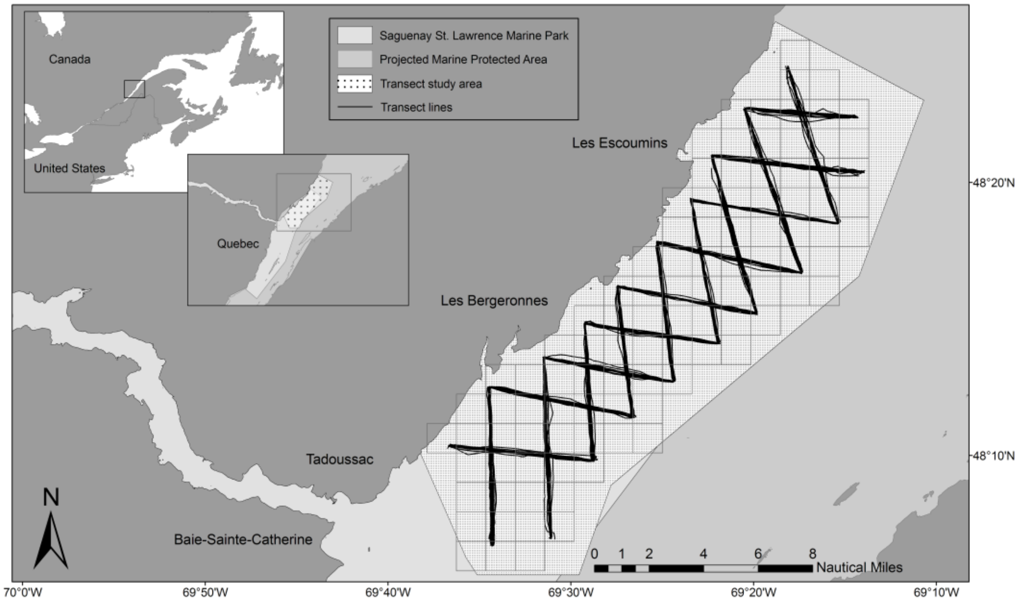


Figure 26. Transect survey study area and grid established to predict baleen whales' density within the marine portion of the St. Lawrence River Estuary.

The selected model for each species was used to predict density over the prediction grid by calling the *predict.gam* function in *mgcv*. The output of the model was an estimate of the predicted count of whales groups in each grid cell, based on each cell's explanatory variables. The predicted count was divided by the area of the grid cell in order to map each species' density of groups. Abundance of each species was calculated as follows:

$$\hat{N} = \sum_{i=} \quad * \bar{s}$$

by summing the predicted count of each cell n_i and multiplying it by expected group size $\bar{s}$ obtained from the size-bias regression in the detection function modelling step

(Buckland *et al.* 2001) presented in Chapter 2.

5. Model validation

A main assumption of the model is that residuals are independently distributed. Spatial autocorrelation was investigated through a variogram analysis (Dalla Rosa *et al.* 2012) using the *geoR* package v.1.6-22 for R (Ribeiro and Diggle 2001). Violation of the independence assumption was assessed by comparing the empirical variogram of deviance residuals with the Monte Carlo envelope of the empirical variogram computed from 400 independent random permutations of the residuals (Diggle and Ribeiro 2007).

6. Variance estimation

A nonparametric bootstrap was performed in order to calculate the variability of the prediction estimates (Hedley and Buckland 2004). A survey day was selected at random, with replacement, to form a new data set with the same number of survey days. Then a GAM was fitted and a prediction was calculated using the same parameters as the GAM selected with the original data set. The bootstrap was repeated 1000 times. The coefficient of variance (CV) of the prediction was calculated and the average for each grid cell was plotted. The bootstrap was performed with a function written for this purpose in R 2.10.1 (R Development Core Team 2009) (see Annexe 1). Confidence intervals (95% CI) were extracted using the percentile method from the bootstrap fitted values.

3.2.5 Model extrapolation

Due to the critical conservation status of blue whales and the need to identify the species core areas outside the survey limits an extrapolation grid covering the whole marine portion of the SLRE from the northern coast up to the isobaths of 50 m, and from Tadoussac up to Betsiamites (Figure 27) was built. Contrary to the prediction grid described above, which interpolated density between track lines, the extrapolation grid extrapolates density beyond the survey region. Such analysis is advisable only as an exploratory analysis (Hammond 2010). The results of the extrapolation were compared with other databases of the species in the study area for validation purposes.

Two databases collected independently were used to validate the extrapolation exercise: telemetry data (Doniol-Valcroze *et al.* 2011; Doniol-Valcroze *et al.* 2012) and boat-based focal follows. Original data corresponded to 12 tracks of whales tagged with a VHF transmitter from 2002 to 2006. The VHF tracks provided a coordinate for each surface sequence of the animal, which corresponded to a position each 5-10 min. Boat-based focal follows were conducted by Meriscope from Portneuf-sur-Mer in 2005 and 2006. They used a whale watching boat as an opportunistic research platform. At each whale encounter, the animal was photographed in order to obtain its individual identification. Time and position were recorded using a hand held GPS (GWS 1984), as often as possible. Positions were accompanied by a visual estimation of the distance of the animal to the boat. Only animals within less than 1 km from the boat were kept for the validation. Also, original data was filtered in order to keep only one position at approximately each 10 min interval. The minimum interval between consecutive positions was of 5 min.

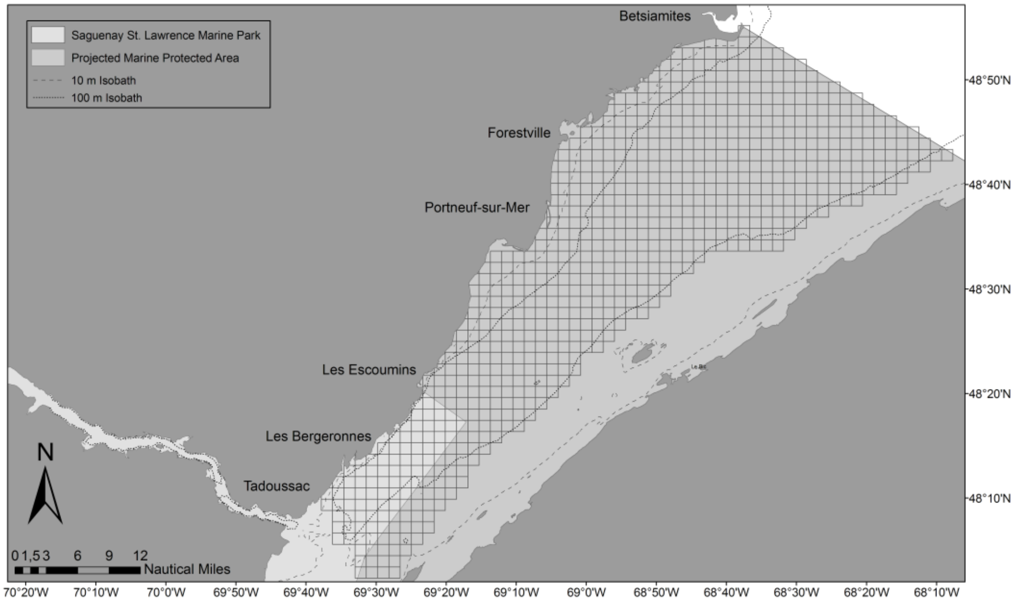


Figure 27. Grid adopted to extrapolate blue whales' density within the marine portion of the St. Lawrence River Estuary from Tadoussac to Betsiamites and delimited by the 50 m bathymetric contour.

3.3 Results

After splitting the transect lines, a total of 2350 segments were available to build the SDM. One survey day (the 5th September 2008) was excluded from the analysis because the track was missing. Table 10 shows the number of sightings (count) of each species available for modelling as well as the detection probability, effective strip width and mean group size. The minke whale was the species with the highest number of records, followed by fin, blue and humpback whales, respectively.

Table 10. Total sightings of each baleen whale species available to fit the spatial density model and the adopted values for detection probability ($\hat{p}$), effective strip width (*w*) and mean group size.

Species	**Sightings**	$\hat{p}$	***w* (km)**	**Group size**
Minke	332	0.33	1.4	1.03
Fin	189	0.56	1.6	1.8
Blue	45	0.472	2	1.04
Humpback	28	0.562	2	1.23

Survey effort covered the whole tidal cycle, but was higher from 8 to 12 hours after the low tide, or during the ebb tide (Figure 28). Considering only the days with at least one sighting of minke whales (Figure 29) the effort was almost homogeneous along the tidal cycle, with a slight peak between the ebb and the low tide. A higher number of surveys with presences of fin whales were conducted from 6 up 12 hours after low tide. For blue whales, surveys had a slight peak at the high tide, from 6 to 9 hours after low tide, while surveys in the presence of humpback whales presented two peaks, one from flood to high tide (from 4 to 8 hours after the low tide) and another from ebb to low tide (three hours preceding the low tide).

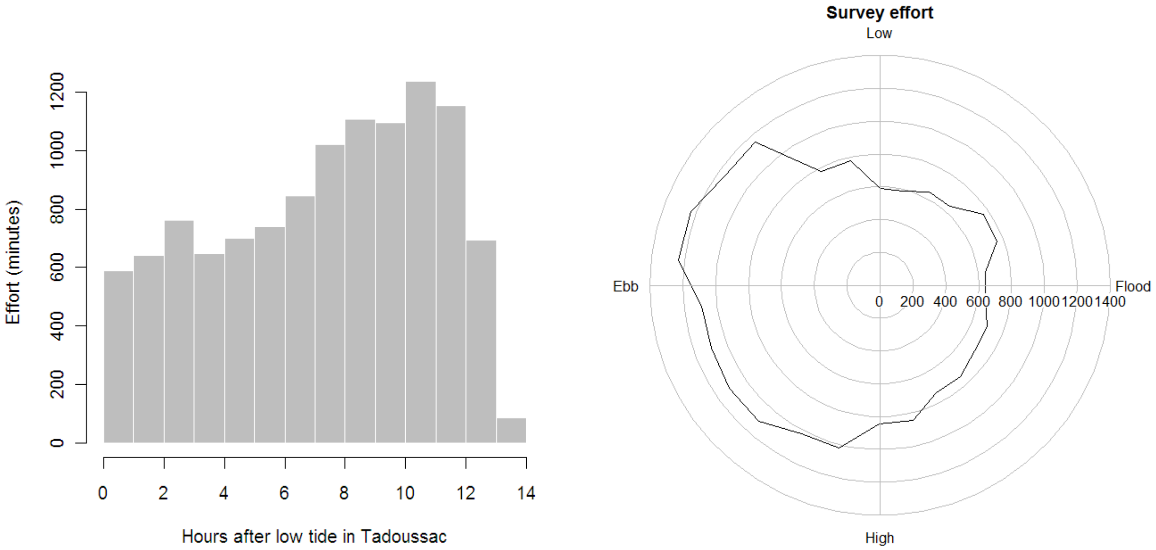


Figure 28. Distribution of the survey effort (in minutes) in relation to the tidal cycle.

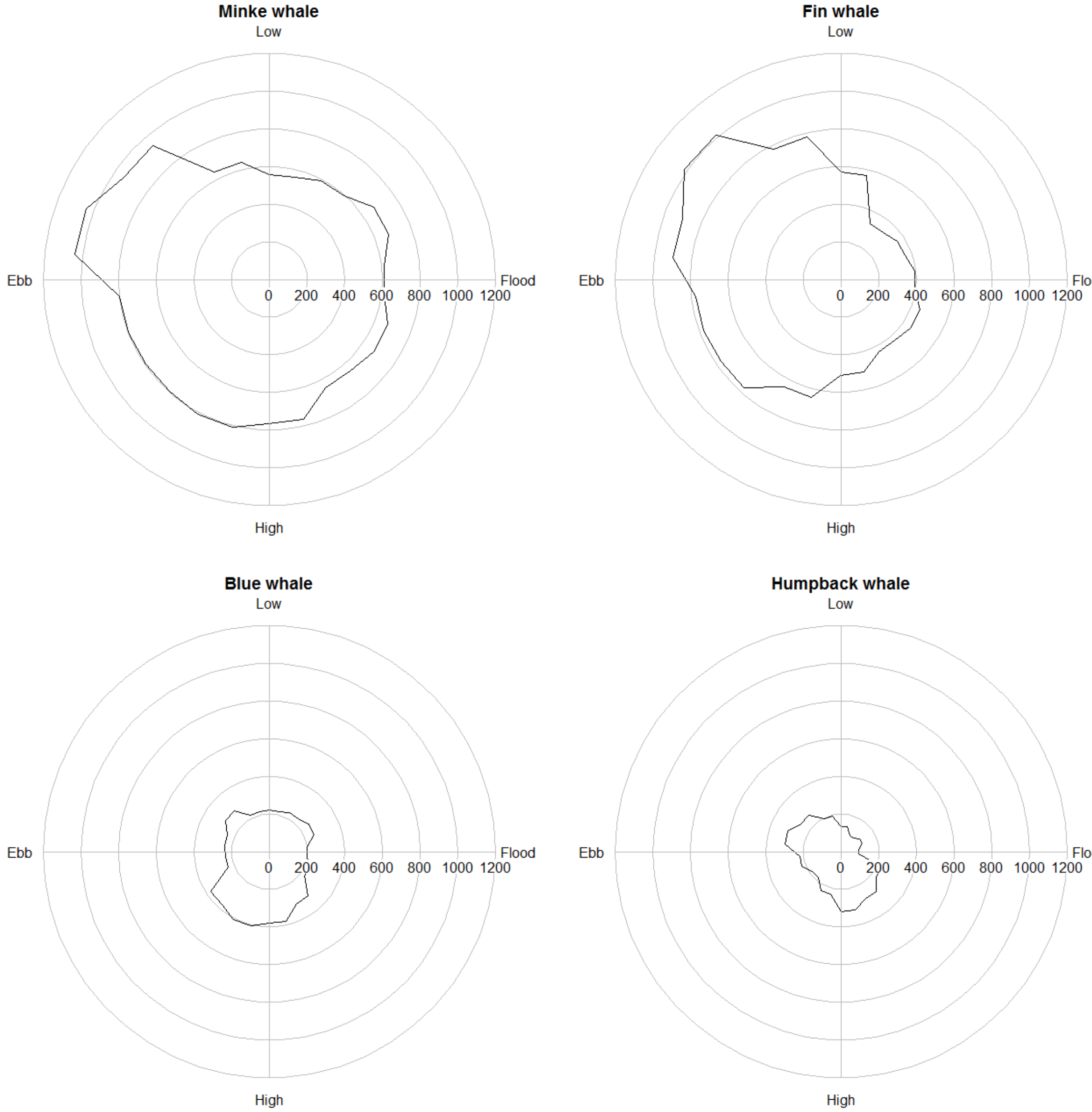


Figure 29. Distribution of the survey effort (from 0 to 1200 minutes) in relation to the tidal cycle for survey days with at least one presence of each baleen whale species.

Figure 30 shows the distribution of the spatial and environmental variables considered to build the SDM. *Longitude*, *Latitude* and *Coastline distance* presented almost a normal distribution while *Depth* and *Slope* presented a skewed distribution. The index of correlation among the environmental variables and the variance inflation index (VIF)

(Table 11) guided the inclusion of variables in the models to be tested. *Latitude* was not included in the models as it was highly correlated with *Longitude* (0.9) and *Depth* (0.7). *Slope* and *Slope_SD*, and *Slope_SD* and *Depth_SD* were also correlated with each other and were not included in the same model (Table 11). *Depth* and *Slope* within the study area can be visualized in Figure 31. A zoom of the bathymetry is provided in Figure 32, which also shows important features that will be used to present the SDM results.

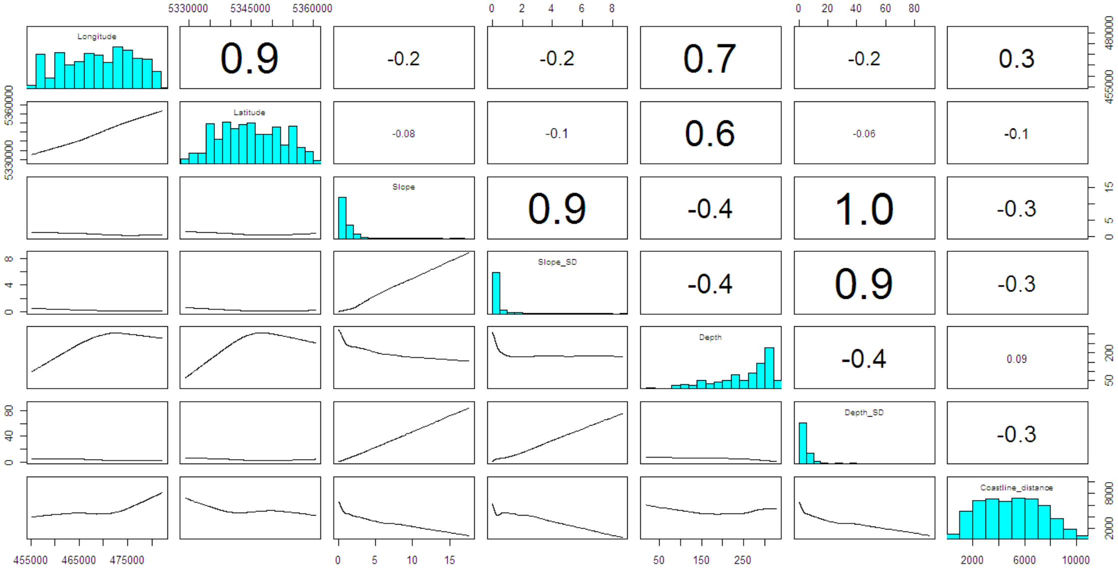


Figure 30. Distribution and correlation of the spatial and environmental variables used in the spatial density model of baleen whales.

Table 11. Variance inflation factors for the environmental variables used to model baleen whales density within the SLRE.

Variable	GVIF	GVIF
Longitude	2.388250	2.392778
Slope	1.890309	-
Slope SD	-	1.835099
Depth	2.899684	2.865822
Coastline distance	1.443187	1.440563

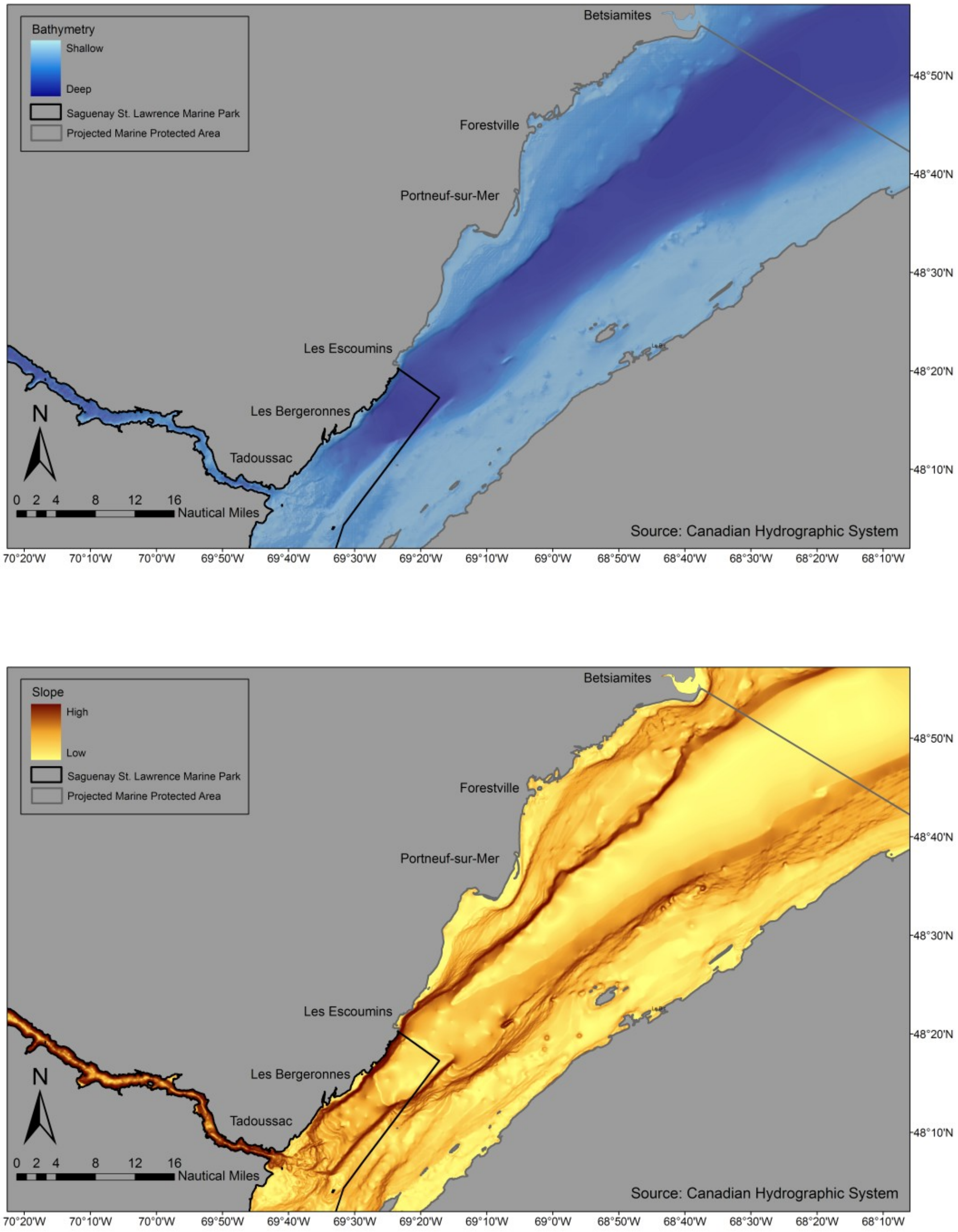


Figure 31. Bathymetry and slope within the marine portion of the St. Lawrence River Estuary.

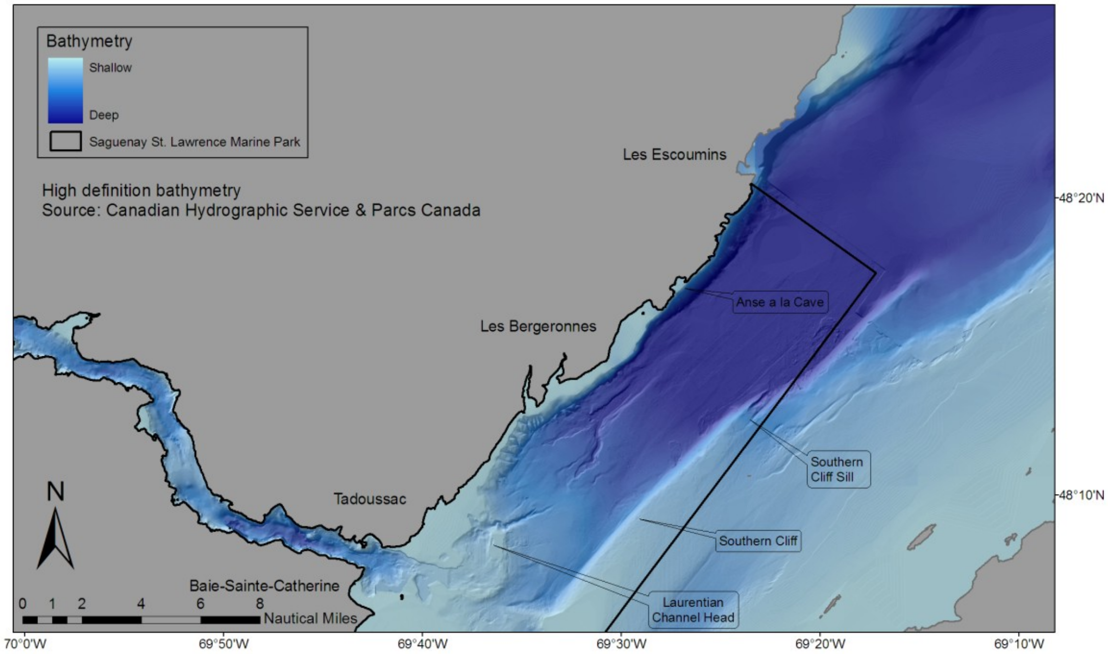


Figure 32. Zoom of the bathymetry within the marine portion of the Saguenay–St. Lawrence Marine Park and indication of important topographic features.

3.3.1 Spatial Density Model

3.3.1.1 Minke whales

For minke whales, the best GAM included *Longitude*, *Slope_SD*, *Depth* and *Coastline distance* (Figure 33). All smooth functions for the retained model indicated nonlinear relationships (Table 12). Minke whales count decreased with the longitude, or from up to downstream. Minke whales were associated with abrupt slopes, and count increased from deep to shallow waters. Counts were associated with the north shore, decreased at the middle of the channel, to increase again around eight km from the coast. The model explained 34.4% of the deviance and had a R^2 of 12.3%.

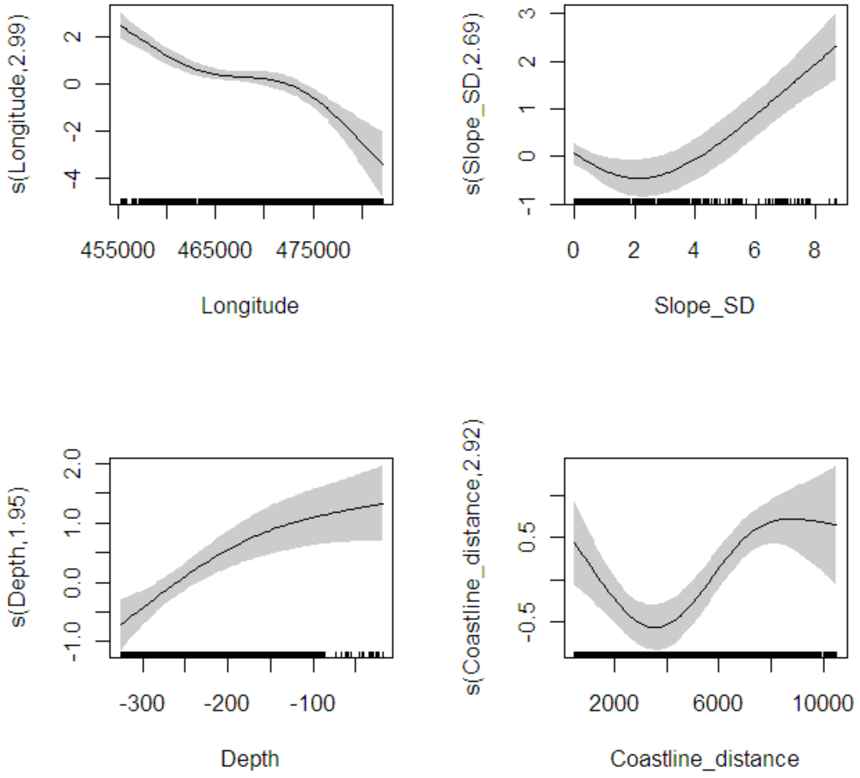


Figure 33. Plots of the GAM smooth fits of the environmental covariates selected for minke whales. Solid lines represent the best fit, the gray area represents the confidence limits, and vertical lines on the x-axis are the observed data values.

The predicted SDM of minke whales (Figure 34) highlighted core areas following the submarine cliffs and forming a “U” at the Laurentian Channel Head, but with higher densities at the north shore than in the southern cliff. The highest CVs were along the downstream portion of the study area.

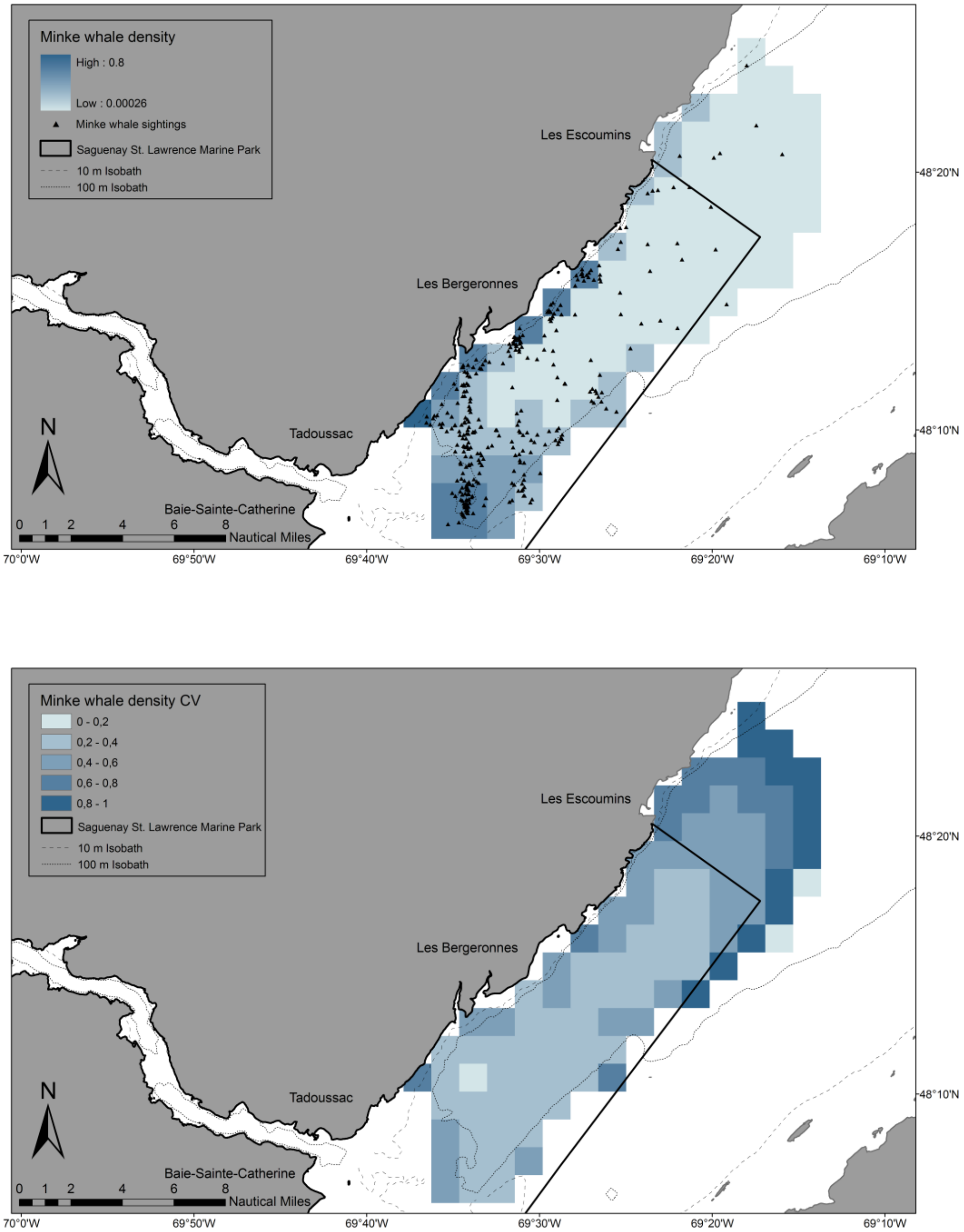


Figure 34. Surface map of minke whales predicted density of groups using generalized additive models (above) and the coefficient of variation (CV) of the prediction (below).

The variogram of the residuals of the minke whales' prediction model (Figure 35) indicates the presence of spatial autocorrelation. Autocorrelation of the residuals was stronger at short distances, or from three to five km. The boxplot (Figure 36) illustrates a high variability in the estimates of density and abundance depending on the random set of transects that composed the bootstrap (outliers are not shown). The mean density of groups was estimated to be 0.069 groups/km^2 with a total abundance of 28 (95%CI: 21-39) minke whales (CV: 22.3%) (Table 13).

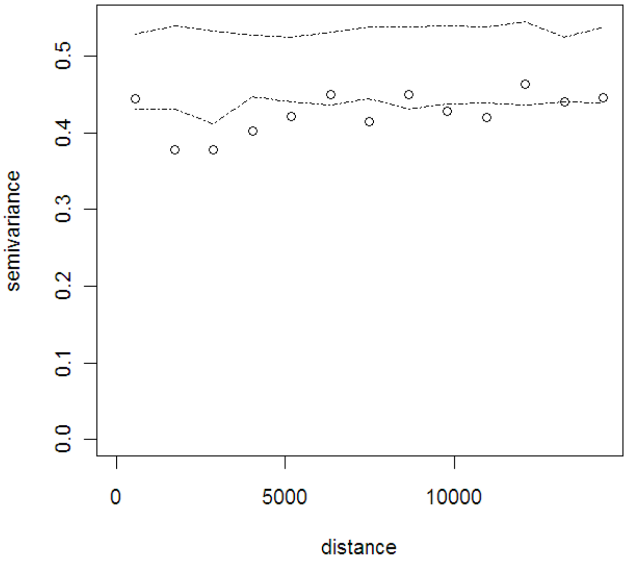


Figure 35. Presence of spatial autocorrelation in the residuals, mainly at short distances (3 - 5 km), with the variogram of the residuals of minke whales' prediction model and the Monte Carlo envelope.

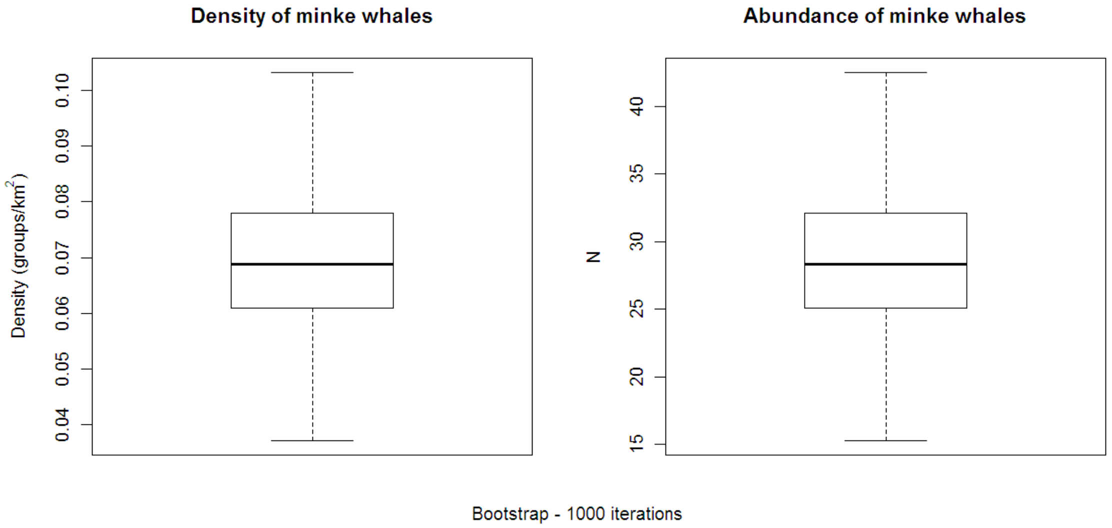


Figure 36. Boxplot of the predicted density and abundance of minke whales derived from the bootstrap.

3.3.1.2 Fin whales

For fin whales, the best GAM included *Longitude*, log of *Slope*, square root of *Depth* and *Coastline distance* (Figure 37). All smooth functions for the retained model indicated nonlinear relationships (Table 12). Fin whales count decreased with the longitude, or from up to downstream, with one peak around 465 000 of longitude. Fin whales were associated with abrupt slopes, and with the bathymetric contours between 100 and 200 m, while counts dropped in shallow waters and deep waters (300 m). Counts were lower at the middle of the channel, from 4 to 6 km from the coast.

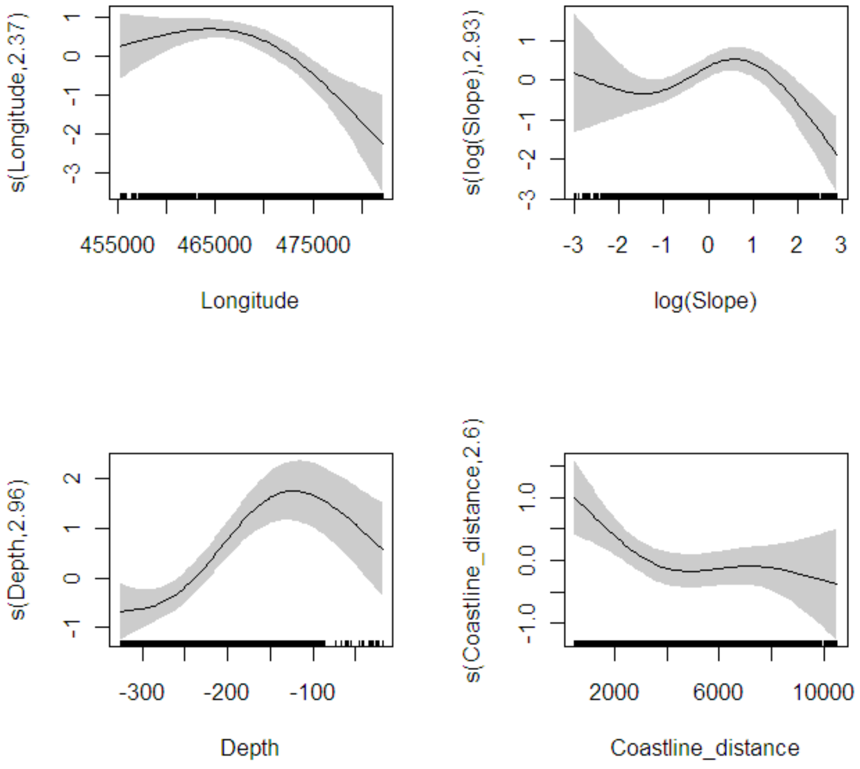


Figure 37. Plots of the GAM smooth fits of the environmental covariates selected for fin whales. Solid lines represent the best fit, the gray area represents the confidence limits, and vertical lines on the x-axis are the observed data values.

The predicted SDM of fin whales (Figure 38) highlights core areas describing a "U", in between the bathymetric contours of 100 and 200 m, from Les Bergeronnes at the north cliff up to the Head of the Laurentian Channel, continuing in the southern cliff up to the vicinity of the sill. The highest CVs were along the downstream portion of the study area. The higher CVs were greater than 100%.

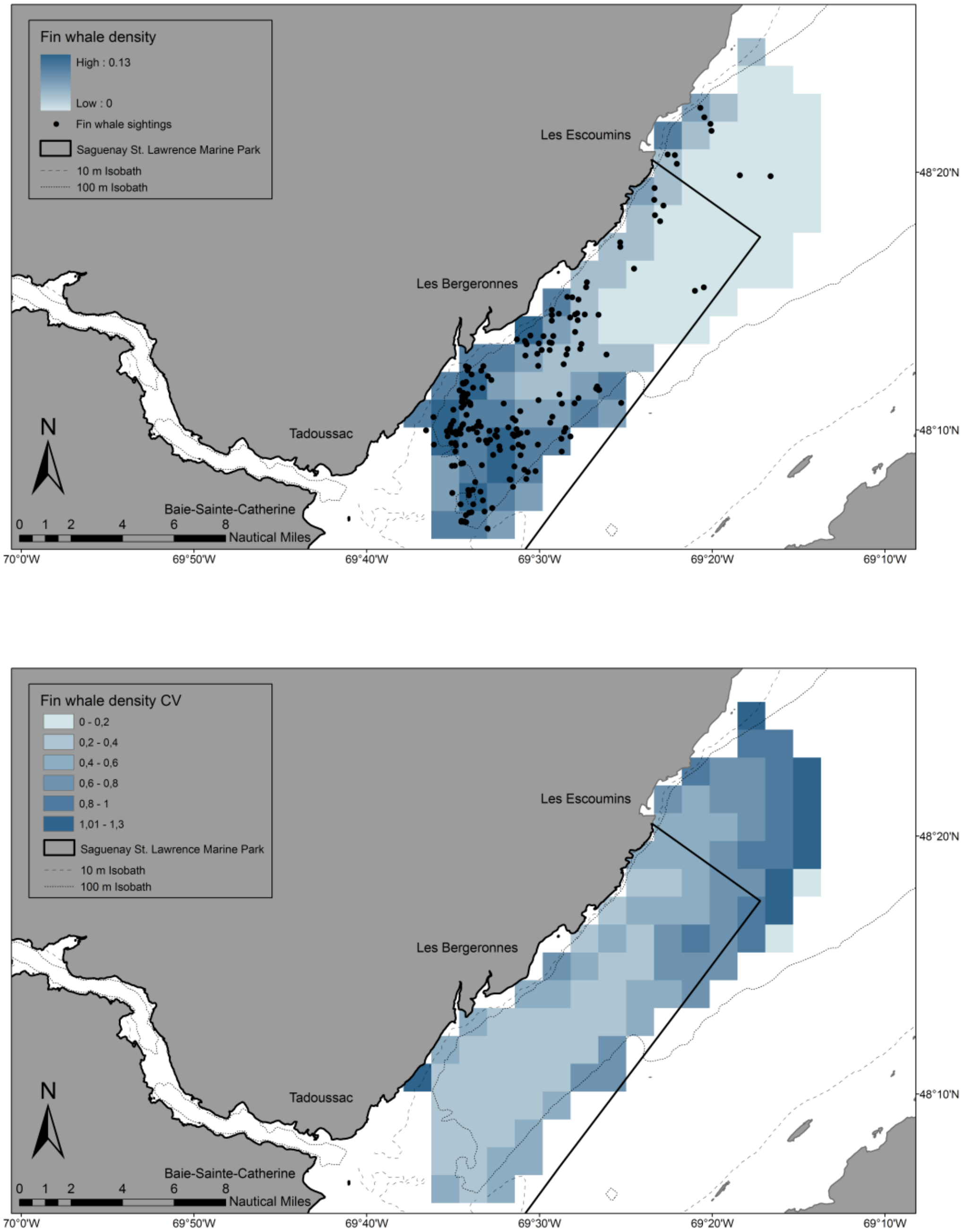


Figure 38. Surface map of fin whales predicted density of groups using generalized additive models (above) and the coefficient of variation (CV) of the prediction (below).

The variogram of the residuals of the fin whales' prediction model (Figure 39) indicates the presence of a weak spatial autocorrelation for short distances. However, most of the points fell within the Monte Carlo envelope. The boxplot (Figure 40) presents the variability in the estimates of density and abundance depending on the random set of transects that composed the bootstrap (outliers are not shown). The mean density of groups was estimated to be 0.026 groups/km^2 with a total abundance of 18 (95% CI: 14-25) fin whales (CV: 18%) (Table 13).

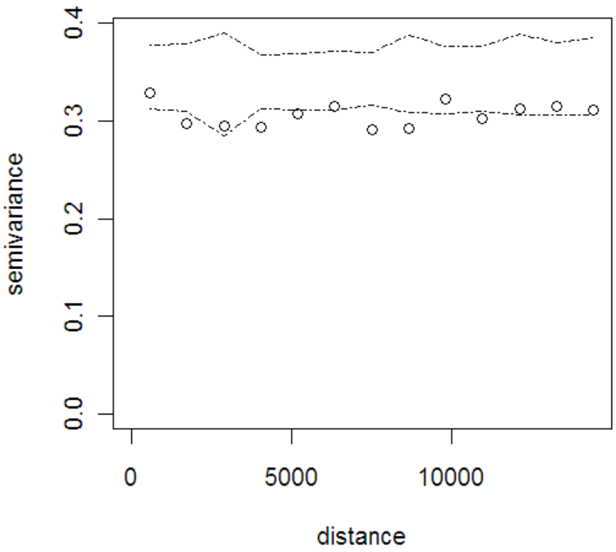


Figure 39. Presence of a slight degree of spatial autocorrelation in the residuals with the variogram of the residuals of fin whales' prediction model and the Monte Carlo envelope.

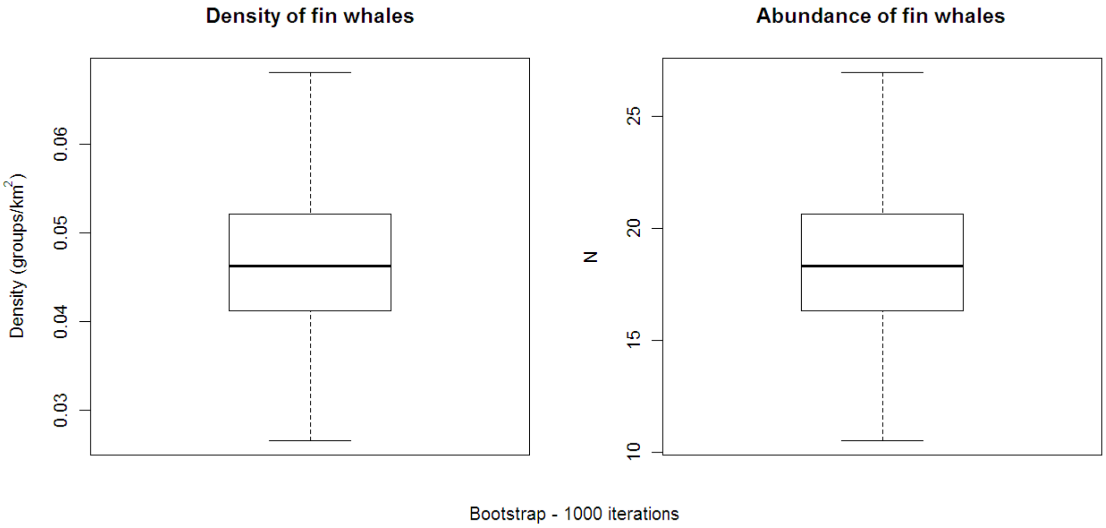


Figure 40. Boxplot of the predicted density and abundance of fin whales derived from the bootstrap.

3.3.1.3 Blue whales

For blue whales, the best GAM included all four variables, with a square root and a log transformation for *Depth* and *Slope*, respectively (Figure 41). All smooth functions for the retained model indicated nonlinear relationships (Table 12Table 12). Blue whales count increased with the longitude, or from up to downstream. Blue whales' were associated with moderate slopes, were in higher numbers in shallow waters up to the 200 m contour. Counts decreased around 2 km from the coast to increase again around 9 km from the north shore.

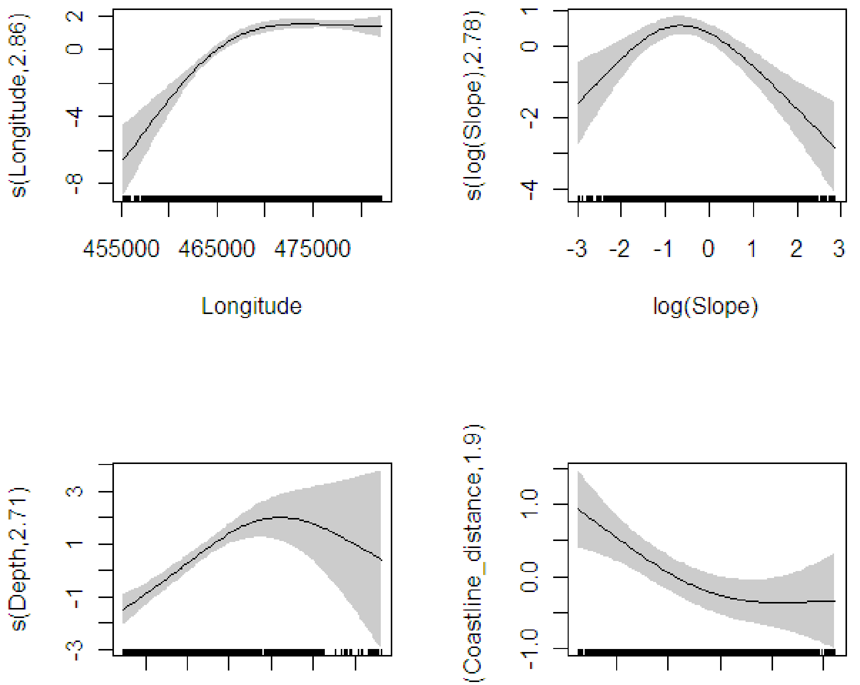


Figure 41. Plots of the GAM smooth fits of the environmental covariates selected for blue whales. Solid lines represent the best fit, the gray area represents the confidence limits, and vertical lines on the x-axis are the observed data values.

The predicted SDM of blue whales (Figure 42) identified the species main core area at the downstream portion of the study area, off Les Escoumins. In addition, a small nucleos was also identified at the vicinity of the southern cliff sill. Most of the study area presented CVs of 40-60%, although some grid cells presented CVs greater than 100% around the Laurentian Channel Head.

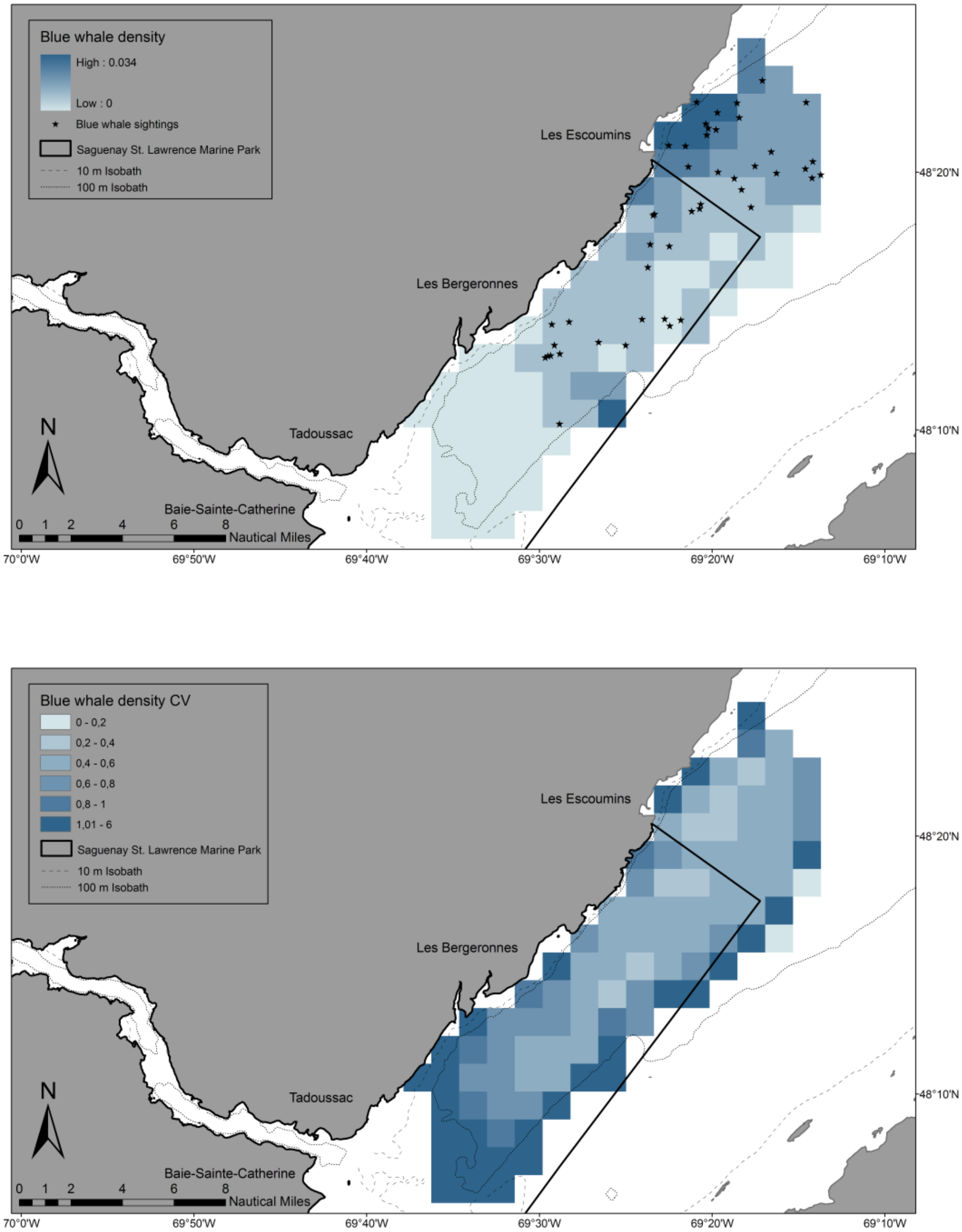


Figure 42. Surface map of blue whales predicted density of groups using generalized additive models (above) and the coefficient of variation (CV) of the prediction (below).

The variogram of the residuals of the blue whales' prediction model (Figure 43) indicates an absence of spatial autocorrelation. The boxplot (Figure 44) presents the variability in the estimates of density and abundances depending on the random set of transects that composed the bootstrap (outliers are not shown). The mean density of groups was estimated to be 0.0055 groups/km^2 with an abundance of 2 (95% CI: 1-6) blue whales (Table 13). Due to the extreme values of CV presented by some grid cells the general CV was greater than 100% (151.2%).

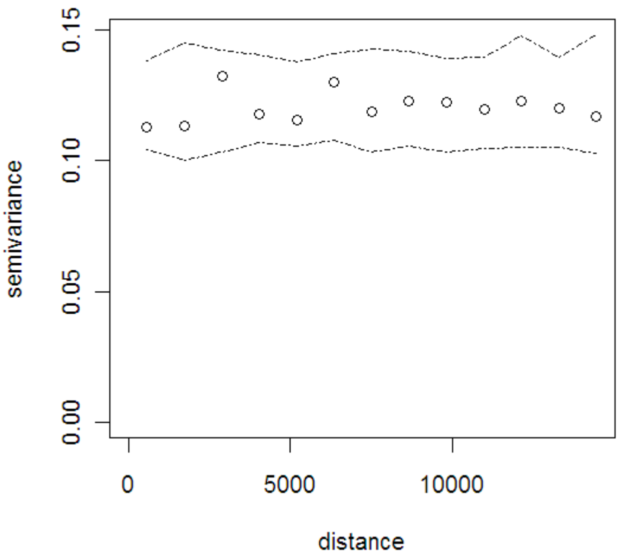


Figure 43. Variogram of blue whales' prediction model residuals' and a Monte Carlo envelope showing the absence of spatial autocorrelation in the residuals.

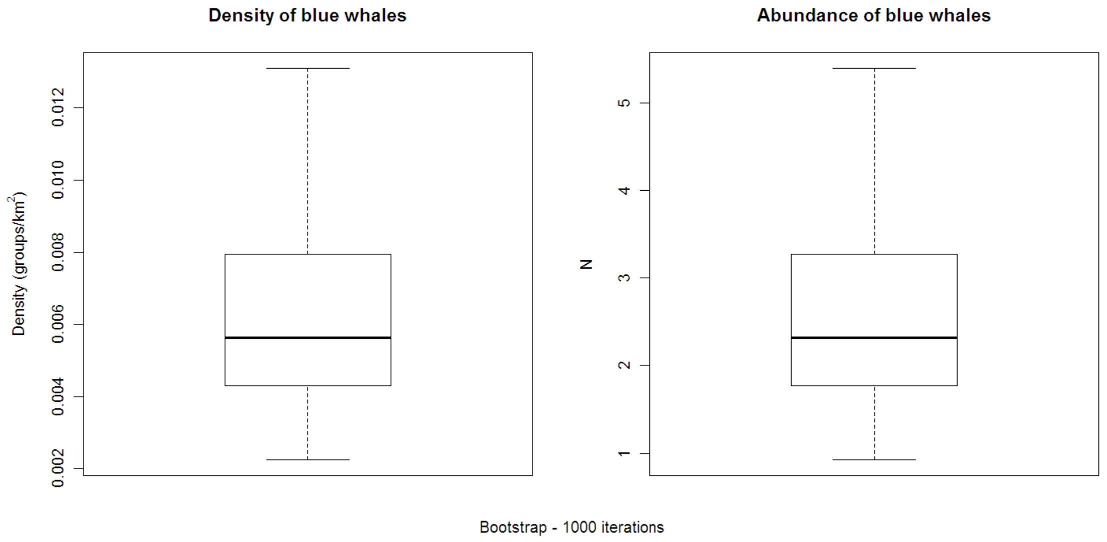


Figure 44. Boxplot of the predicted density and abundance of blue whales derived from the bootstrap.

From the boat-based focal-follows carried out by Meriscope, 531 positions were kept to validate the extrapolation of the blue whale density. Data corresponded to 27 different days between 30th June and 11th October in 2005, and 17 different days between 26th June and 11th October in 2006. The independent datasets, telemetry data and boat based focal-follows, were overlaid over the extrapolation derived from the best GAM model (Figure 45). The high density areas predicted by the extrapolation model range from Les Escoumins up to Betsiamites following the north shore coast line. Most of the points from the independent datasets were within areas of high density predicted by the model.

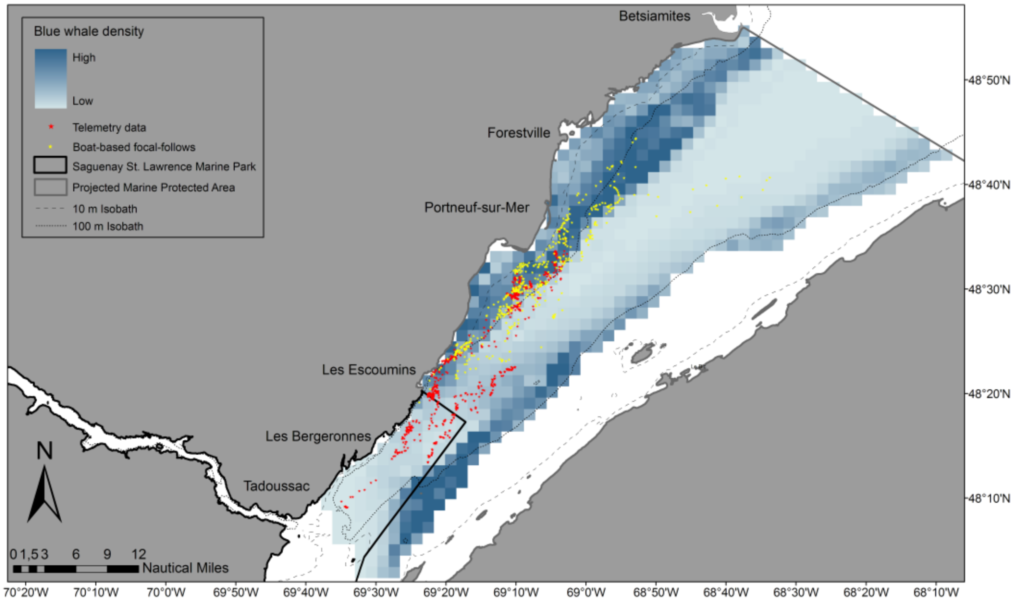


Figure 45. Surface map of the predicted density of blue whales derived from model-based methods extrapolated to the marine portion of the SLRE, and its overlay with independent datasets.

3.3.1.4 Humpback whales

For humpback whales, the best GAM included all four variables without any transformation (Figure 46). All smooth functions for the retained model indicated nonlinear relationships (Table 12). The humpback whales' count presented a peak at the middle of the study area, around 465 000 of longitude. Humpback whales count was low in intermediate slopes, and was associated with depths of 100 and 200 m. Counts were higher up to 4 km from the coast after which they dropped to rise again around 10 km from the north shore.

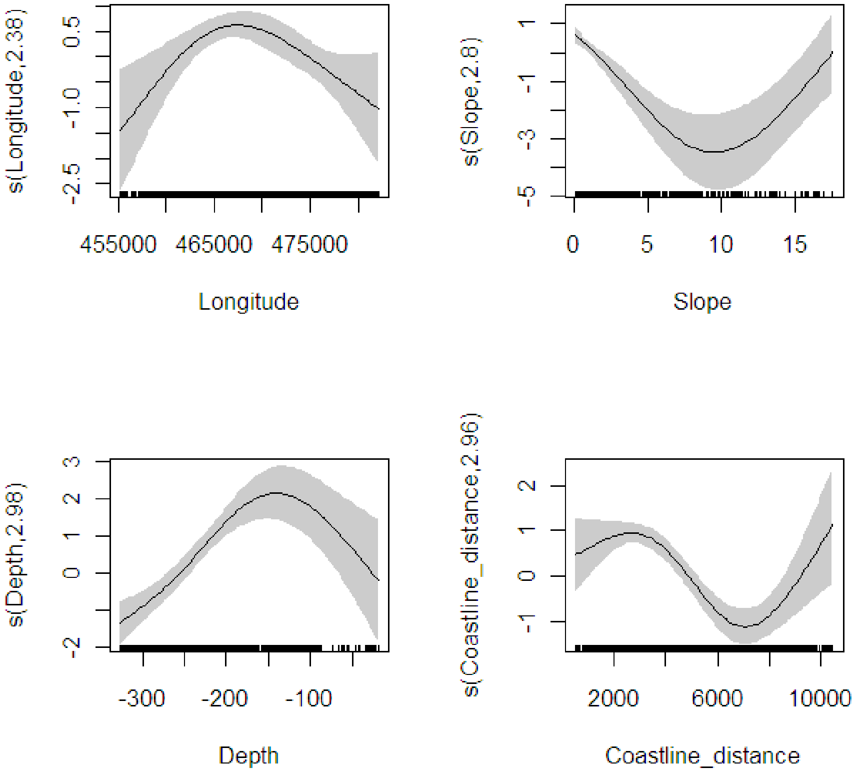


Figure 46. Plots of the GAM smooth fits of the environmental covariates selected for humpback whales. Solid lines represent the best fit, the gray area represents the confidence limits, and vertical lines on the x-axis are the observed data values.

The predicted SDM of humpback whales (Figure 47) identified the species main core area covering the coastal portion (up to 4 nm from the coast) of the Laurentian Chanel Head up to Les Bergeronnes. Some localised hotspots were also present along the north shore up to Les Escoumins and associated with the southern cliff, at the vicinity of the southern cliff sill. Most of the study area presented CVs of 80-100%, although some grid cells presented CVs greater than 100% at the edges of the prediction grid.

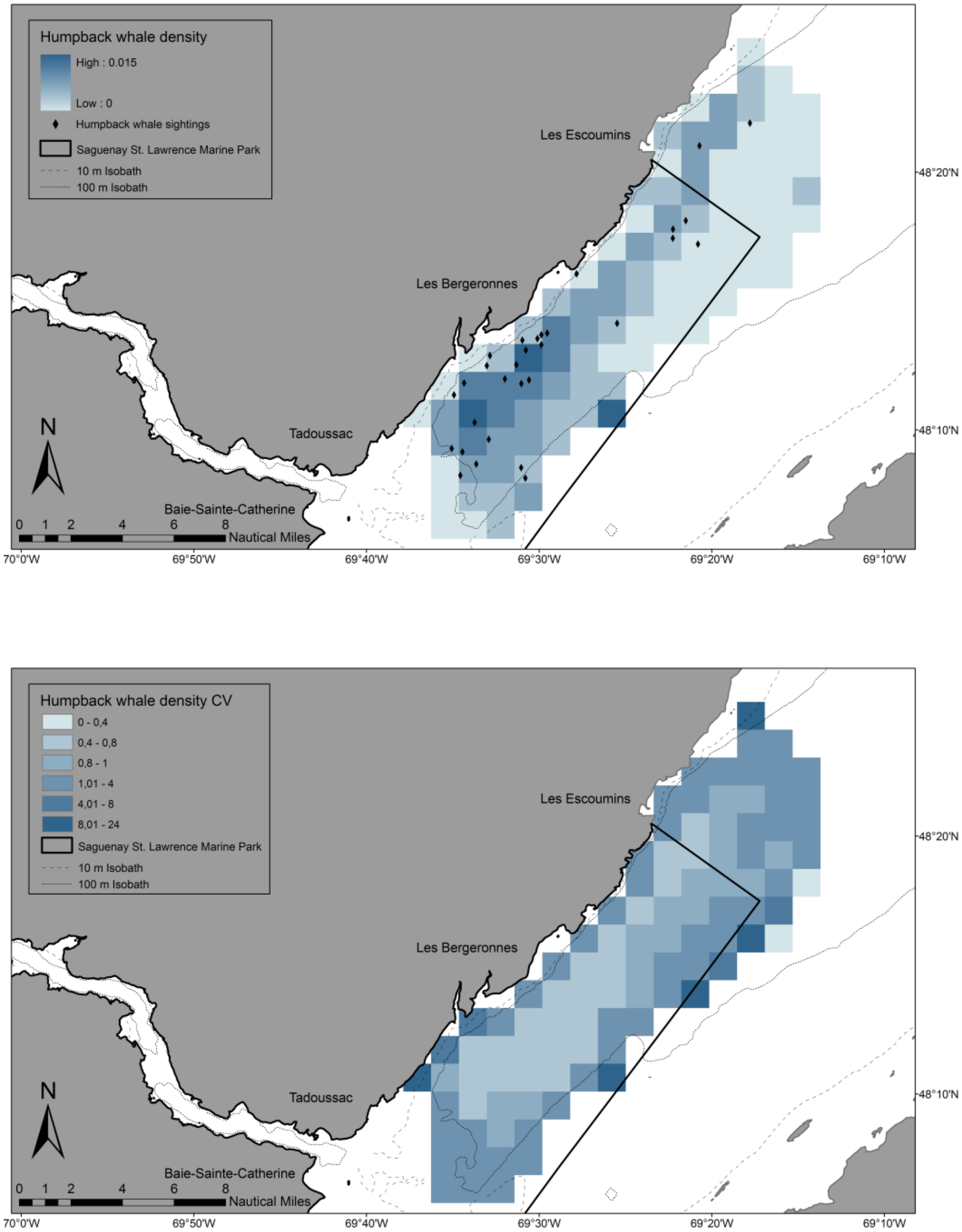


Figure 47. Surface map of humpback whales predicted density of groups using generalized additive models (above) and the coefficient of variation (CV) of the prediction (below).

The variogram of the residuals of the humpback whales' prediction model (Figure 48) indicates an absence of spatial autocorrelation. The boxplot (Figure 49) presents the variability in the estimates of density and abundances depending on the random set of transects that composed the bootstrap (outliers are not shown). The mean density of groups was estimated to be 0.0044 groups/km^2 with an abundance of 3 (95% CI: 1-4) humpback whales. Due to the extreme values of CV presented by some grid cells the general CV was greater than 100% (316%) (Table 13).

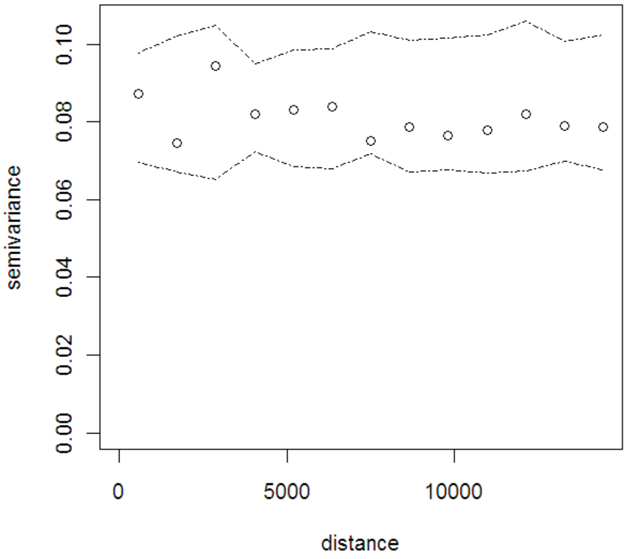


Figure 48. Variogram of the residuals of the prediction model of humpback whales with the Monte Carlo envelope showing the absence of spatial autocorrelation in the residuals.

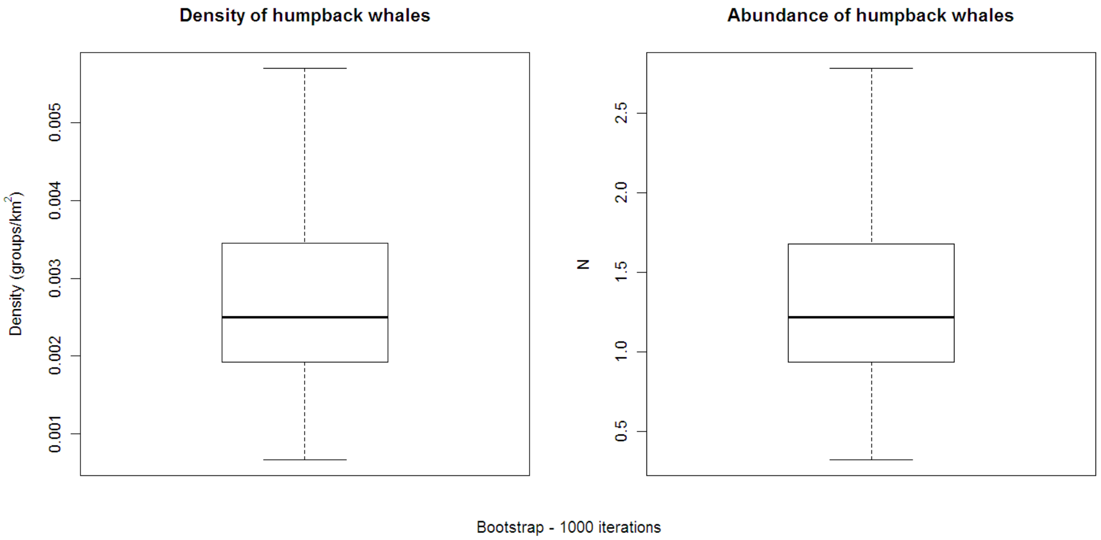


Figure 49. Boxplot of the predicted density and abundance of humpback whales derived from the bootstrap.

Table 12. Spatial and environmental variables retained after model selection for each baleen whale species. **S** indicates the use of a smooth function along with the degrees of freedom and transformation used (if any), both in parentheses. Percent of deviance explained and R^2 adjusted for all models are also presented. * indicates significance level p-value of 0.001, **0.01.

	Smooth (df, transformation)			
Variable	**Minke**	**Fin**	**Blue**	**Humpback**
Longitude	S(2.99)*	S(2.37)*	S(2.86)*	S(2.38)*
Depth	S(1.95, sqrt)*	S(2.96, sqrt)*	S(2.71)*	S(2.98)*
Slope	-	S(2.93, log)*	S(2.78, log)*	S(2.8)*
Slope SD	S(2.69)*		-	-
Coastline distance	S(2.92)*	S(2.6)**	S(1.9)*	S(2.96)*
% Dev. explained	34.4	24.7	11.0	13.2
R^2 Adjusted	0.123	0.07	0.0146	0.0138

3.3.2 Density and abundance estimates

The comparison of the estimates of density and abundance derived from MBM and DBM is presented in Table 13. The average density of groups estimated by both methods was very similar. The abundance estimates cannot be directly compared as the prediction grid was reduced to avoid extreme predictions at the edge of the study area.

Table 13. Estimated abundance (N) and density of groups (D) and the corresponding coefficient of variation (CV%) derived from the spatial density models (SDM) and from conventional distance sampling (CDS) or multi-covariate distance sampling (MCDS) analysis.

	MBM (SDM)			DBM (CDS/MCDS)		
Species	D	N	CI	D	N	CI
Minke	0.069	28	21-39	0.0757	45	34-59
Fin	0.026	18	14-25	0.023	24	18-34
Blue	0.0055	2	1-6	0.0051	3	2-5
Humpback	0.0044	3	1-4	0.0028	2	1-4

3.4 Discussion

Here generalised additive models (GAMs) were used to build spatial density models for four baleen whale species: minke, fin, blue and humpback whales. The use of spatial and fixed environmental variables allowed mapping the density over the space providing some insights about the species' habitat use patterns. Likewise, the core areas, or high density predicted areas, of each species were identified improving our knowledge about the species habitat use and providing adequate support to coastal management. Density estimates derived from MBM were similar to the results obtained with DBM, although only MBM allow the cartography of the density. Gathered results corroborate the adequacy of the survey design implemented and conducted by the GREMM to estimate baleen whale species density and abundance.

3.4.1 By species

3.4.1.1 Minke whale

Minke whales were the most abundant baleen whale species in the marine portion of the SLRE. It is known that their occurrence is recorded over a vast area (DFO 2007) but the SDM of the species showed that their density peaks at specific locations. Along the north shore, minke whales' core areas cover the area from the LCH up to Anse a la Cave (Figure 32). The species was concentrated at the most coastal grid cells, with densities fallen outside the 2 km from the coast. As the species is not a formal target of whale watching (WW) activity within the marine park, longitudinal data collected on board WW boats since 1994 are not a good representation of the species distribution patterns (Michaud *et al*. 2003). And thus, as expected, a very weak match is observed between the two data sources. Besides, most minke whales records derived from WW boats were located at the entry of the Saguenay river which is outside the area covered by the transect survey design up 2009. The new design, adopted in 2010 and 2011, incorporates this area.

The species' prediction model presented the highest adjusted R-square score and percentage of deviance explained. A similar adjusted R square (0.105) was derived from an analogous study conducted in Antarctic waters but that used latitude, longitude and depth as predictors (Williams *et al.* 2006). The species preference for steep slopes has been described for other feeding areas (Naud *et al.* 2003; Ingram *et al.* 2007). Depth and slope were the best predictors to explain the distribution of minke whales at the Bay of Fundy (USA) (Ingram *et al.* 2007). And, as in the SLRE, a preference for steep slopes and depths in between 100 – 200 m was observed (Ingram *et al.* 2007). At Mingan islands (CA) minke whales were associated with steep slopes and underwater sand dunes (Naud *et al.* 2003).

Minke whales are known as solitary species, meaning that they usually do not form groups. However, even if usually solitary, they often occur in high-localised densities. The definition usually adopted to define whales social behaviour is derived from former studies that were mainly dedicated to humpback whales (e.g. Tyack and Whitehead 1983; Whitehead 1983; Baker and Herman 1989; Clapham *et al.* 1992). Based on these definitions, a group is defined as two or more animals swimming in the same direction, at no more than a whale distance apart or at no more than a 100 m apart (depending on the author) and showing synchronised behaviour. Although pragmatic, whales may have coordinated behaviour over distances greater than a 100 m (Whitehead 1983). Recent studies on blue whales in the Gulf of California adopted other spatial scales to understand the social behaviour of blue whales (over a km) (Costa-Urrutia *et al.* 2012). Personal observations corroborate the hypotheses that minke whales at distances greater than a 100 m showed synchronised behaviour. Further studies are needed in order to improve our knowledge of minke whales social behaviour, with possible direct implications to methods used to derive population parameters as density and abundance.

3.4.1.2 Fin whale

Fin whales preference to steep slope contours within the SLRE was first described by Sergeant (1977), which suggested it was a probable consequence of the high biological productivity of these areas due to tidal mixing. Waters of the intermediate layer rise from below 75 m depth to near the surface over the sills with the high tide (Saucier and Chassé 2000). Worldwide, the species show the same pattern of association with areas that favour the accumulation of prey along depth gradients (Woodley and Gaskin 1996; Notarbartolo-Di-Sciara *et al.* 2003; Williams *et al.* 2006). Fin whales are the second largest whale species and their elevated daily energetic requirements justify their strong correlation to areas with dense prey aggregations (Acevedo-Gutierrez *et al.* 2002; Cotté *et al.* 2009).

The core areas identified in the present analysis corroborate the observations of Sergeant (1977) and are consistent with the VHF monitoring of fin whales conducted in the 1990's (Michaud and Giard 1997) and with data collected onboard WW boats (Michaud *et al.* 2003; Michaud *et al.* 2008; Michaud *et al.* 2011). Michaud *et al*. (2003) reported a small-scale displacement from a former preferred habitat at Red Island canyon (southern portion of the LCH) but the lack of information on the prey species distribution patterns precluded any further analysis. The temporal variability of fin whales density within the SLRE was not in the scope of the present analysis, but the inclusion of dynamic variables, and if possible of the prey species, is recommended for studies aiming to predict the species' occurrence in the area or to test hypotheses about their fine scale habitat use patterns.

Fin whales present a marked daily displacement pattern within the study area governed by the tide cycle (Giard *et al.* 1998). At the high tide the animals tend to be concentrated along the cliffs, while at the low tide they are more dispersed over the territory. A similar pattern was also reported in the Gulf of Maine (Johnston *et al.* 2005), where the species occurrence was associated with the flood tides. Besides the presence of a daily pattern, Giard *et al.* (2001) found a strong negative correlation between the krill standing stock biomass and their spatial distribution and dispersion index (mean number of sightings within 2 km radius). Fin whales were less aggregated in years with high krill biomass and were more aggregated in years with low krill biomass. Furthermore, while feeding on krill they tend to be solitary and while feeding on fish, they tend to form large groups (R. Michaud personal communication). These findings support the hypothesis that krill abundance influences their aggregation behaviour (Giard *et al.* 2001). In the present analysis, group size variation was not taken into account. Including group size (e.g. Ferguson *et al.* 2006) in a future exercise might improve the model robustness.

3.4.1.3 Blue Whale

Blue whales are usually associated with upwelling systems or frontal areas (Croll *et al.* 1998; Fiedler *et al.* 1998; Palacios 1999; Hucke-Gaete *et al.* 2004; Branch *et al.* 2007; Doniol-Valcroze *et al.* 2007; Gill *et al.* 2010) and show preference for steep slopes (e.g. Croll *et al.* 1998; Branch *et al.* 2007). Despite the low sample size, the SDM of blue whales corroborates the results of the long-term monitoring conducted onboard WW boats in the area (Michaud *et al.* 2003; Michaud *et al.* 2008; Michaud *et al.* 2011) and found by Doniol-Valcroze and colleagues (2012). The later, predicted areas of high suitability for blue whales based on the analysis of 10 animals tracked with VHF. The high suitability areas (HS>0.8) identified in their study match the high-density areas predicted by the SDM.

Most of the high-density areas predicted by the SDM are at the border of the SSLMP, and the extrapolation exercise revealed important habitats with similar characteristics from les Escoumins to Betsiamites, which is at the limit east of the proposed MPA. Although, the high-density areas derived from the SDM extrapolation exercise showed a good match with the raw tracks from Doniol-Valcroze *et al*. (2012) and with the animals tracked from WW boats by Meriscope, there is a lack of research effort in part of the extrapolation grid area. The extrapolation exercise identified areas of possible importance to the species along the 200 m bathymetric contour along the southern cliff. A recent report produced with the long-term database kept by the MICS, which conducts photo-identification studies of the species since 1979, also suggests the SLRE as an important habitat for the species (Comtois *et al.* 2010).

The species critical status requires urgent action in order to guarantee the species recovery. Additional studies are required in order to identify the species critical habitat in the Canadian waters (Beauchamp *et al.* 2009). In the absence of better data, the extrapolation exercise here presented provides valuable information to guide the discussion of management scenarios that aim to enhance the quality of the historic habitats used by the species. Besides, the SDM itself highlight the importance of the creation of the proposed St. Lawrence Estuary marine protected area, as the existent marine park does not include the totality of the essential habitats used by this endangered species.

3.4.1.4 Humpback whale

Humpback whales occur in very low number in the study area (Mitchell *et al.* 1982; Edds and Macfarlane 1987). Early records of the species sightings at the marine portion of the SLRE come from land based observations conducted from 1972 through 1975 (Mitchell *et al.* 1982). Since that time, the species has been observed almost every year but it was only from 1999 on that their presence inside the Marine Park begins to be more continuous and not episodic (Michaud *et al.* 2003) suggesting the reoccupation of a pre-whaling feeding habitat.

The North Atlantic humpback whale population is considered recovered from the commercial whaling and actual population size is above the pre-whaling estimates (Reilly *et al.* 2008). Fidelity to the feeding areas has been described for the species, and is possibly influenced by maternal transmission (Weinrich *et al.* 2006). Once the mother returns from the breeding area with her calf of the year, the feeding area, feeding style and prey preference are transmitted. A possible explanation for the low number of animals observed in the SLRE is that the animals using this feeding area were exclusively males, what kept the abundance low for a long period. The first humpback whale calf observed within the SSLMP was *Aramis*, the calf of *TicTacToe* that was first sighted in 2007 (Baleines en direct 2012). In 2012, *TicTacToe* was recorded in the area with another calf. Not only resident females are now at the reproductive age and will start to bring newborns to the area, as other young animals were observed for long periods in the area (e.g. Perseides and Blanche-Neige, Baleines en direct 2012). In 2012 the first observation of *Blanche-Neige* in the area was early in May and the last was in mid November (R. Pintiaux, personal communication).

The SDM of humpback whales matches well with data collected onboard WW boats (Michaud *et al.* 2003; Michaud *et al.* 2008; Michaud *et al.* 2011; Baleines en direct 2012) even if the prediction model presented a high number of cells with elevated CV. Besides the low number of sightings available to build the model the plasticity of the species behaviour might have increased the variance observed. Humpback whales shown markedly state behaviours that might be associated with distinct habitats, in other words, areas used for feeding and for resting activities should be different, contributing to the observed spatial variability. Doniol-Valcroze *et al*. (2012) claimed the use of behaviour states to improve habitat use models. However, data to conduct such analysis is often lacking. Despite the low number of records and resulted adjusted R square, the spatial model presented 13.2% of the deviance explained. Williams *et al.* (2006) found an adjusted R square of 0.129 and a deviance explained of 36.1 for humpback whales in Antarctic waters from opportunistic surveys.

3.4.2 Baleen whales spatial density models

The SDMs obtained provide valuable information for the management of this portion of the territory, essential information that was lacking. The results corroborate the importance of the LCH as a main feeding aggregation mainly for minke and fin whales. Blue whales' core areas were essentially at the downstream limit of the SSLMP and within the proposed SLEMPA. Humpback whales' core areas were somewhat overlapped with minke and fin whales. The four species use the study area as a feeding ground and with the exception of blue whales that feed exclusively on krill, they share the same prey species. However, to date, no information about the diet of each species is available. Whales diet can be inferred using fatty-acids from blubber samples and stable isotopes (carbon and nitrogen) from skin samples (*e.g.* Hooker *et al.* 2001; Lesage *et al.* 2001) and an analysis was planned using existent biopsy samples of fin whales (R. Michaud, personal communication). Minke, fin and humpback whales demonstrate some ability to switch between different prey items depending on their availability and thus, annual samples would allow a better understanding about the species diet and of the ecosystem dynamic across the time.

Preliminary analysis of the prey monitoring survey conducted by the SSLMP since 2009, resulted in a higher concentration of fish (*e.g.* capelin and sand lance) in shallower waters (up to the isobath of 100 m) at the LCH while the main patches of the two krill species, *Thysanoessa raschii* and *Meganyctiphanes norvegica*, were found in the deeper waters area, mainly at the down-stream portion of the marine park (Turgeon and Ménard *in prep*.). Their results correspond well to the distribution of fin and blue whales, respectively. Within this portion of their range, the core areas used by fin and blue whales were contiguous but not overlapped. In the GSL, the niche used by fin, blue and humpback whales was overlapped in the space (Doniol-Valcroze *et al.* 2007) but no information about the temporal habitat partitioning was available. Appropriate studies focusing the habitat partitioning of these large marine predators are encouraged.

In Antarctic waters, Clapham and Brownell (1996) suggest that competition between the baleen whale species is unlikely due to probable resource partitioning mediated by food preferences and potentially the biomechanics of body size. Sympatric humpback and minke whales in Antarctic waters showed a similar horizontal distribution, but vertically, humpback whales were associated with krill aggregations in the upper portion (≤133 m) of the water column, while minke whales were associated with deeper krill aggregations (Friedlaender *et al.* 2009). Minke whales' association with deeper krill patches in Antarctic is believed to be independent of the presence of other species, supporting a feeding specialisation (Friedlaender *et al.* 2009). VHF tracking was applied to blue and fin whales in the study area and are now being used to describe the vertical feeding behaviour of the other baleen whale species that occur within the SLRE. Combined with the prey monitoring survey and with analysis of their diet they will allow a better understanding of the species ecology. As the whales' presence in the area is guided by the availability of their prey, these aspects of their ecology are essential to an in depth understanding of the system dynamic. The actual scenario of an imminent global change, with signals that have already been detected in the area (e.g. reduced ice cover during the winter, decreasing concentration of oxygen in the lower water masses, increasing frequency of red tides (e.g. Gilbert *et al.* 2005; Ménard 2007)) stress the need to a multidisciplinary approach to the better understanding and consequent better management of this fragile ecosystem.

3.4.3 Modelling considerations

Spatial density models are still in their infancy. Much still need to be developed in order to improve model fit performance and adequacy. Some aspects deserve to be highlighted and observed in future analysis. Model selection was not problematic but without limiting the degrees of freedom the model prediction presented signals of overfitting. Some authors suggested the use of a basis dimension (k) of eight (what limits the model degrees of freedom to seven) (Dalla Rosa *et al.* 2012). However, for the SLRE the use of k=8 resulted in overfitting and large variances for all species. Other studies suggest the use values of k similar to the adopted here (Clarke *et al.* 2003; Ferguson *et al.* 2006)

GAMs allow modelling the relation between the species and the environment as non-linear, however, due to their flexibility care must be taken in order to avoid overfitting. The adopted model selection methods assume that the observations are independent, and lack of independence could also result in overfitting. Overfitting should not bias the population estimates, although can raise the variance (Augustin 1999; Clarke *et al.* 2003). Choice of *df* reduce the possibility of overfitting. An alternative approach would be to take the spatial auto-correlation into account using mixed models (Zuur *et al.* 2009), for example. This approach should be envisaged for fin and minke whales, for which spatial autocorrelation of the residuals was verified. In addition, it would be interesting to investigate the effect of zigzag versus parallel design to reduce spatial autocorrelation.

Although the results were appropriate, all models presented a low explanatory value. Previous studies using GAM to build SDM highlight that overdispersion is a possible explanation for the low explanatory value of such models (De Segura *et al*. 2007). In the present analysis, the high number of zeros (*i.e.* the high number of transect segments *l* with none observation assigned) imposed the use of a quasi-poisson distribution to account for the overdispersion. Williams *et al*. (2011) modelled the abundance of blue whales in Chile using a Twedi distribution, which the authors suggest to be more appropriate to accommodate the effects of overdispersion of this kind of data than the quasi-poisson distribution. Zuur *et al.* (2009) advocate the use of zero-inflated models that had become more accessible with the recent advances in modelling techniques.

Spatial autocorrelation in the residuals was identified for minke and fin whales using the Monte Carlo envelope. The envelope establishes the minimum and maximum values that a random residual should have and thus the points outside the envelope indicate the presence of pattern in the residuals. Hedley and Buckland (2004) also detected autocorrelation in the residuals for minke whales in the Antarctic. The authors suggested this might be true autocorrelation possibly due to the species social behavior or to simple variation due to covariates that have not been measured. Although the presence of autocorrelation in the residuals does not invalidate the fitted model, modelling techniques that allow accounting for autocorrelated data (Zuur *et al.* 2009) are of interest. Recent advances in the development of mixed models are of interest, as they must be extended for use with line transects data (Hedley and Buckland 2004). The inclusion of other variables would also be appropriate.

Attempt was made to include dynamic variables in the prediction model, but the scale of the available data precluded their inclusion. Satellite image data are usually available at a resolution of four km and data from the local circulation model (Saucier and Chassé 2000) were available at a resolution of five km (D. Lefaivre, personal communication). Although, this resolution would not be appropriate to the scale of the environment (Hedley and Buckland 2004). In situ data would be the best solution to have oceanographic data to include in future modelling analysis. Fine scale (~ 1 km) data from the circulation model would also improve the model. It is important to highlight that the use of dynamic variables limits the prediction to specific environment configurations (Redfern *et al.* 2006).

3.4.4 Variance estimation

Variance in spatial density models is usually estimated using re-sampling techniques as nonparametric (as used here) or parametric bootstrap (Hedley and Buckland 2004), moving-block bootstrap (Clarke *et al*. 2003) and Jacknife (Williams *et al.* 2006). All the above-mentioned methods yield unstable and biased results unless a large number of independent samples is available (Williams *et al.* 2011). Here each transect day was used as unit to be re-sampled. It was assumed that each survey day was independent of the others, an assumption that holds for most survey days. Surveys were planned to take place three times per week in non-consecutive days. However, as survey effort is weather dependent some surveys took place in consecutive days, possibly affecting the independence assumption. Moving-block bootstrap would possible perform better as it allows to accommodate the correlation between counts from segments close in the space and time by taking into account the strength of autocorrelation between observations (Clarke *et al.* 2003). Another possibility would be the use of a Bayesian approach that was suggest by Wood (2006) and recently implemented by Williams *et al*. (2011) to estimate the variance of blue whale abundance derived from SDMs.

The chosen technique, nonparametric bootstrap, performed well for the abundant species, and although the variances were higher than those obtained with DBM methods, they were reasonable. Indeed, as minke and fin whales are the most abundant species, they are the ones to which autocorrelation between consecutive days must be more important (also a possible explanation for the presence of autocorrelation in the residuals for these species - see modelling considerations discussion). The use of the moving-block bootstraps should improve the variance estimates for these species. This method is actually being implemented in a R package developed by Dave Miller (package dsm) and must be available soon.

Even if a large number of segments were available to bootstrap, the variance analysis for the rare species resulted in an overall high coefficient of variation. The later was mainly due to extreme values at the edge of the study area. Attention while defining the prediction grid must minimise the edge effect (Williams *et al.* 2006). As mentioned by several authors, SDM variance estimation is an unresolved statistical issue that should experience improvements in the near future (Hedley and Buckland 2004; Hedley *et al.* 2004; Williams *et al.* 2006).

3.4.5 Density and abundance estimates derived from MBM

As it was expected, the results of density and abundance obtained with MBM and DBM in the previous chapter were quite similar. The average density of groups was of the same order and the differences in abundance were due to the reduced area covered by the prediction grid. The preliminary analysis were run with a prediction grid that had a similar area to the polygon used in the chapter 2, however, as some grid cells were outside the range of the observer it resulted in extreme values of CV for all species. In the final prediction grid, all grid cells that were not completely within the buffer of 2km around the transect lines were eliminated, originating the surface difference. As the abundance in the MBM is the sum of each cell predicted density, by modifying the prediction grid dimension, the density does not change, but the abundance is adjusted in consequence.

It was not in the purpose of the present analysis to predict density and abundance for each year, for shorter time intervals (within the season), or for smaller areas. Indeed, if this information is required for management purposes the use of MBM instead of DBM is recommended. MBM have the power to improve robustness of the estimates and even more in the case of stratified analysis (Hedley *et al.* 2004), be the stratification in the space or in the time. Such stratified analysis is encouraged only for minke and fin whales. Gathered results corroborate the adequacy of the survey design implemented and conducted by the GREMM to estimate baleen whale species density and abundance.

3.4.6 Management implications

The results confirm the importance to create the St. Lawrence Estuary MPA in order to enhance the protection of the essential habitats used by the endangered blue whale. Gathered results might guide the discussion of measures aiming to decrease the exposure of the baleen whales to anthropogenic threats and to ensure the conservation of their core areas. In the next chapter, the prediction maps will be used in order to verify the degree of overlap of baleen whales core areas with an important navigation corridor that crosses the study area.

Chapter 4

Sharing the space: identifying overlaps between baleen whales' distribution and maritime traffic at the marine portion of the St. Lawrence River Estuary

4.1 Introduction

Maritime traffic has increased over the last century while our knowledge about the functioning of marine ecosystems has also been evolving. Ship lanes were placed to optimize benefits for transportation without taking into account ecosystem management and conservation priorities. Nowadays, not only the amount of data about marine ecosystems has increased but also different tools are available to improve landscape and seascape management. Geographic Information Systems (GIS), for example, are a major tool for landscape management and planning (Goodchild *et al.* 1992; Goodchild and Haining 2004; Matthies *et al.* 2007). Coupled with the fast developing field of ecological informatics, many hybrid models - the integration of multiple modelling approaches and technologies across the disciplines to represent the structures and dynamics of ecosystems – have been developed to guide decision-making in natural resource management (Parrott *et al.* 2011). In the previous Chapter, the first spatial density model of baleen whales' distribution in the study area was presented. Here, GIS capabilities will be used to verify to which degree whale distributions are overlapped by the navigation corridor that crosses the study area.

The St. Lawrence River Estuary (SLRE) is crossed by the most important ship lane of the eastern Canadian coast. The SLRE is the main entry for importations and exit for exportations of the eastern Canada and has historically been important for the development of the North American midcontinent (Taylor and Roach 2009). Large ship traffic within the SLRE is intense and might double in the coming years (Ircha 2005). Although of high importance, the only information to date to characterize the volume of maritime traffic that crosses the marine portion of the SLRE comes from a recent study carried out by Chion et al. (2009).

Chion et al. (2009) provided the first complete characterization of the maritime traffic for the year of 2007 (May 1st to October 31st) within the Saguenay St. Lawrence Marine Park (SSLMP). In their report, a complete description and quantification of all boat types that use the area is provided. Large ship traffic represented the third component in terms of importance, after the whale watching industry (13 073 excursions) and the ferry boats (22 541 transits) that link the villages of Baie-Sainte-Catherine and Tadoussac, at the mouth of the Saguenay River. A total of 3 135 transits were recorded within the studied period by more than 650 different ships (*i.e.* cargo ships, tankers and tug/tows). To characterize the large ship traffic, Chion *et al*. (2009) used AIS data and prevision data from the Information System on Marine Navigation (INNAV) of the Canadian Coast Guard. The map showed in figure 50 (adapted from Chion *et al.* 2009) illustrates the ship traffic intensity for the marine portion of the SSLMP.

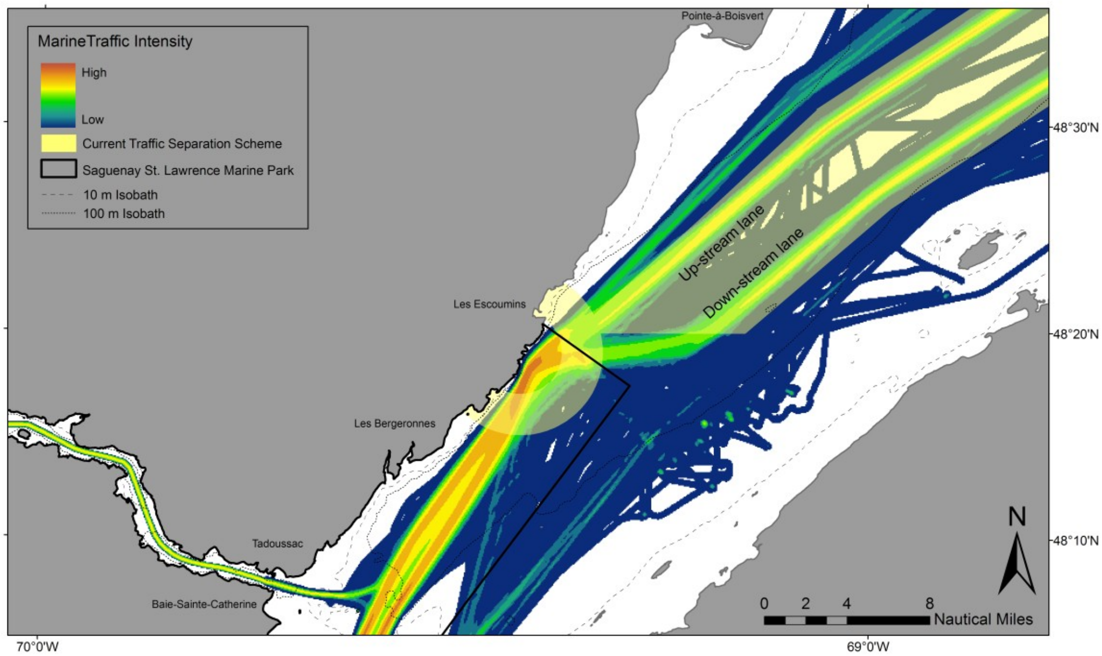


Figure 50. Intensity of large ship traffic within the marine portion of the Saguenay - St. Lawrence Marine Park (Adapted from Chion *et al*. 2009) and the current traffic separation scheme.

The position of the shipping lanes that cross the SLRE are determined by the traffic separation scheme (TSS), which by its turn follows international rules adopted by Transport Canada (Transport Canada 1991). The TSS is usually adopted where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea–room, the existence of obstructions to navigation, limited depths or unfavourable meteorological conditions (Transport Canada 1991). In recent years, an increasing number of alterations to TSSs have been proposed in order to decrease the exposure of marine mammals to the effects of intense marine traffic (Kraus *et al.* 2005; Merrick and Cole 2007; NOAA 2011; IWC 2012).

It is known that ship strikes (Figure 51) are an underestimated threat to cetacean species. In 2007, the International Whaling Commission (IWC) designated an *ad hoc* committee to evaluate the impact of this activity to cetacean species (IWC 2011). Worldwide the issue has been discussed by multipartite groups concerned with the activity (e.g. Kraus *et al.* 2005; NOAA 2011). In the SLRE, a similar initiative was recently undertaken. A multiparty working group was created in 2010 by the initiative of managers working in the SLRE. The working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* - G2T3M) is composed of navigation experts, members of the maritime industry, scientists, and members of non-governmental and governmental organizations. The aim of the group was to find solutions to reduce the collision risk within the marine portion of the SLRE (G2T3M *in prep*).

Figure 51. Fin whale strike in California - USA (Bernardo Alps/PHOTOCETUS).

In the first phase of its existence, the members of the group used different tools (e.g. GIS) to characterize the exposure of marine mammals to traffic in the area and in addition adopted a bottom-up model – 3MTSim – recently developed (Parrott *et al.* 2011) to test different management scenarios. The 3MTSim is a decision support system that has been developed to inform management and planning in the SLRE (Parrott *et al.* 2011). The system allowed testing different management scenarios for the marine traffic (e.g. speed limits, lanes modification) in order to assess their possible effects on navigational patterns and on marine mammals' exposure. After two years of discussion of multiple scenarios the working group agreed on the recommendation of a set of provisional measures (Figure 52) (G2T3M *in prep*). Three different zones were proposed: a cautionary zone which covers the estuarine waters in between the isobaths of 30 m; a speed reduction zone and an area to be avoided (G2T3M *in prep*). In this chapter, besides verifying the degree of overlap between whale distributions and the navigation corridor, the effectiveness of the provisional measures recommended by the working group (G2T3M) to reduce collision risk within the SLRE will be discussed.

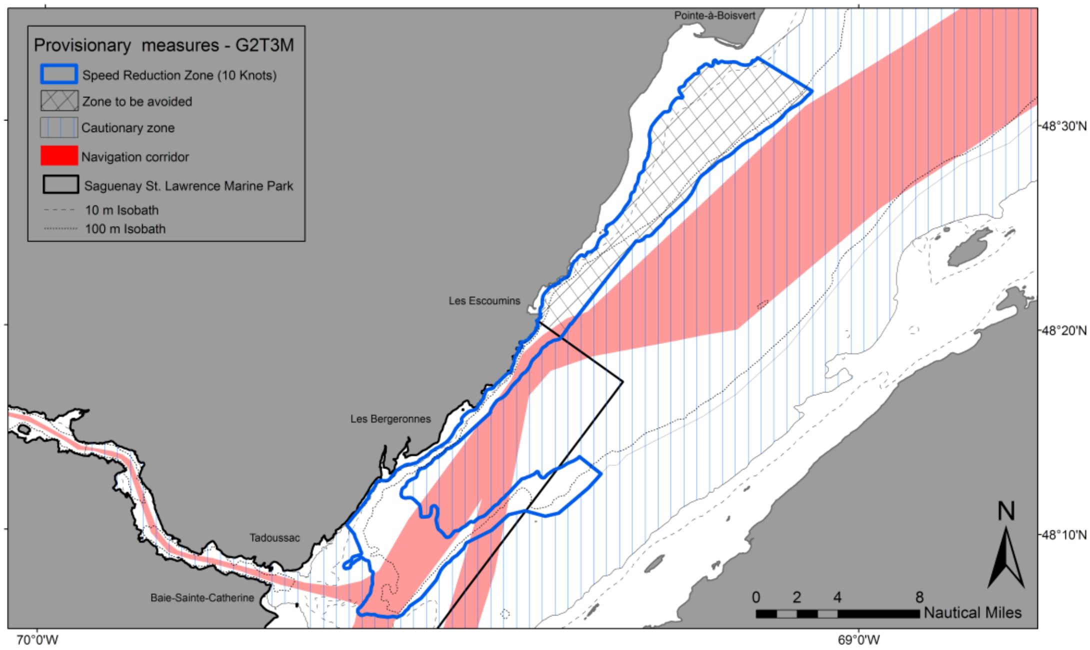


Figure 52. Provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M) to reduce collision risk within the St. Lawrence River Estuary.

4.2 Material and Methods

4.2.1 Spatial density model of baleen whale species

The spatial density model (SDM) resulted from the analysis presented in the previous Chapter was used here. It was assumed that the SDM of each species is the best model of the species density during the feeding season, and thus the high density cells represent well the core areas used by each baleen whale species in the area. The estimated densities were normalised by species (the value of each cell was divided by the maximum predicted density of each species).

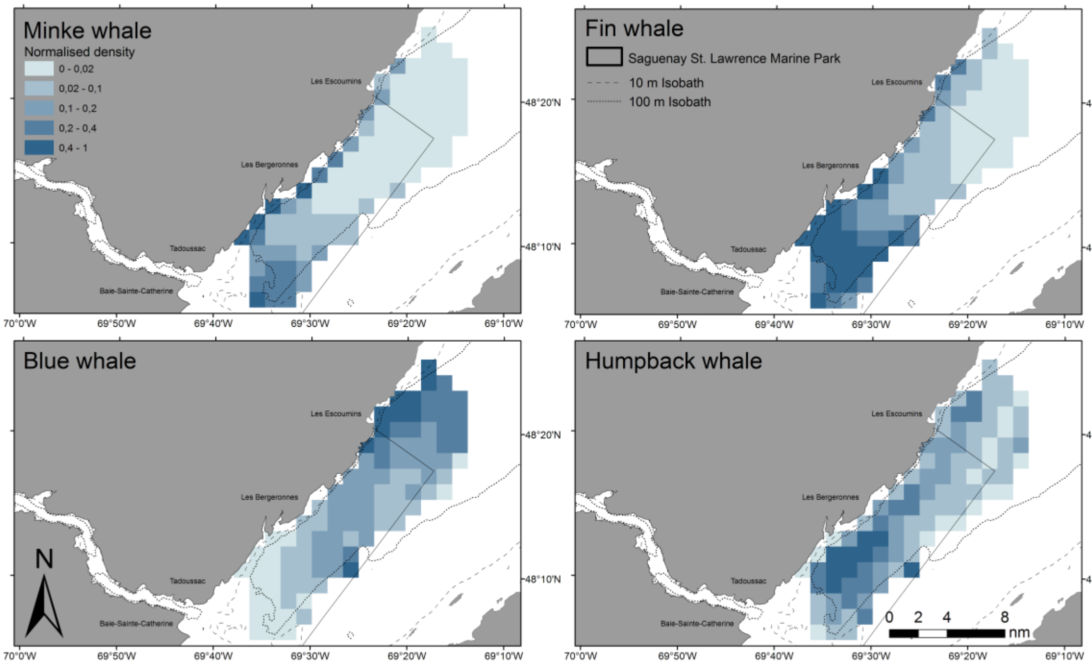


Figure 53. Baleen whales' spatial density models derived from line transect distance sampling surveys conducted from 2006 to 2009 within the study area.

As the conservation status of each baleen whale is different, a weight was assigned to each species based on its status in order to discriminate the areas in which a high density of endangered species occurs. The status of each species as determined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2012) was adopted and a subjective weight was attributed to each category (Table 14). The normalised predicted density of each species was multiplied by the weight of the corresponding category and this new field was used to perform the co-occurrence risk analysis.

Table 14. COSEWIC conservation status of each baleen whale species occurring in the study area and weight adopted for the risk analysis.

Category	**COSEWIC definition**	**Weight**	**Species**
Endangered	A wildlife species facing imminent extinction	4	Blue whale
Threatened	A wildlife species likely to become endangered if limiting factors are not reversed.	3	-
Special concern	A wildlife species that may become a threatened or an endangered wildlife species because of a combination of biological characteristics and identified threats.	2	Fin whale
Not at risk	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances	1	Minke whale; Humpback whale

The co-occurrence risk analysis was performed by species and for all species combined (grouped analysis) using the prediction grid. Due to the critical conservation status of the blue whale, the risk analysis for this species was performed with the prediction grid and with the extrapolation grid. It is important to highlight that the extrapolation grid, even if validated by independent data sets, was not validated in its whole extension.

For the grouped analysis the following operation was performed:

$$\text{Grouped SDM} = \sum_{i=1}^{n} (D_{s,i} w_s)$$

where:

i = a cell of the spatial grid (n cell)
D = Normalised density
s = Species (minke, fin, blue and humpback whales)
w= Weight as presented in Table 14

All GIS operations were performed using ArcGIS 9.3.

4.2.2 Ship traffic intensity

In order to characterise the ship traffic intensity in the study area two grids were used: the prediction grid (covering the marine portion of the SSLMP) and the extrapolation grid (covering the marine portion of the SLRE). Part of the original data analysed by Chion and colleagues (2009) was used. The original dataset was necessary as the rasterized map of ship intensity presented by Chion *et al.* (2009) was incomplete outside the SSLMP. The original database represented more than 95% of the large ships transiting in the area for the period from May 1st to October 31st of 2007 (Chion *et al.* 2009) and presented some spatial gaps downstream from Les Escoumins. The database AIS-INNAV of the Canadian Coast Guard is composed of consecutive positions that are received at each minute while the ship is in the range of the reception station. Each position is accompanied by the ship identity, type, speed, and direction, among other variables.

The AIS-INAVV data base was used to calculate the number of ships that crossed each grid cell from May 1st to October 31st of 2007. This period covers the arrivals and departures of most baleen whales in the area. For each grid cell the number of ship transits was calculated without distinction of direction. The AIS dataset was not complete (*i.e.*

missing tracks and spatial gaps) when compared to the prevision data from the INNAV database. In order to ensure that the volume of traffic was correct, a weight was defined for each boat category (*e.g.* tanker, tug) based on the INNAV database. The weights were attributed for all complete trajectories crossing the entire study area, to correct for the missing tracks.

4.2.3 Co-occurrence risk

In order to quantify the co-occurrence risk the SDM was multiplied by the grid of ship intensity. The higher the species density and the ship intensity, the higher the co-occurrence value attributed to the grid cell. In order to facilitate the interpretation of the results, the co-occurrence risk was classified into five categories (Table 15). The choice of categories limits was subjective and they are only valid for the study area (*i.e.* they are not meant to be compared to other areas with different volumes of traffic).The same analysis was performed by species, using the grouped SDM and the extrapolation model of blue whales density.

Table 15. Categories adopted to represent the co-occurrence risk of whales and ships within the study area.

Co-occurrence Risk	Co-occurrence value
Very low	0 – 100
Low	100 -500
Moderate	500-1000
High	1000-2000
Very high	>2000

4.2.4 Management solutions

In order to explore possible management solutions to decrease baleen whales' co-occurrence with the ship traffic in the area adjustments to the current traffic separation scheme were proposed based on the co-occurrence risk maps. In addition, the provisionary measures recommended by the working group on marine mammals and maritime traffic were overlapped with the co-occurrence risk maps in order to verify the effectiveness of such measures based on the presented results.

4.3 Results

4.3.1 Co-occurrence risk

The analysis by species revealed areas of *moderate* to *very high* co-occurrence risk for all species (Figure 54). Co-occurrence risk with minke whales was only identified at the southern portion of the Laurentian Channel Head (LCH), where a *high* co-occurrence cell was identified. For fin and blue whales a large number of cells were classified as *high* and *very high* co-occurrence areas. For humpback whales a *high* co-occurrence area was identified off Les Bergeronnes.

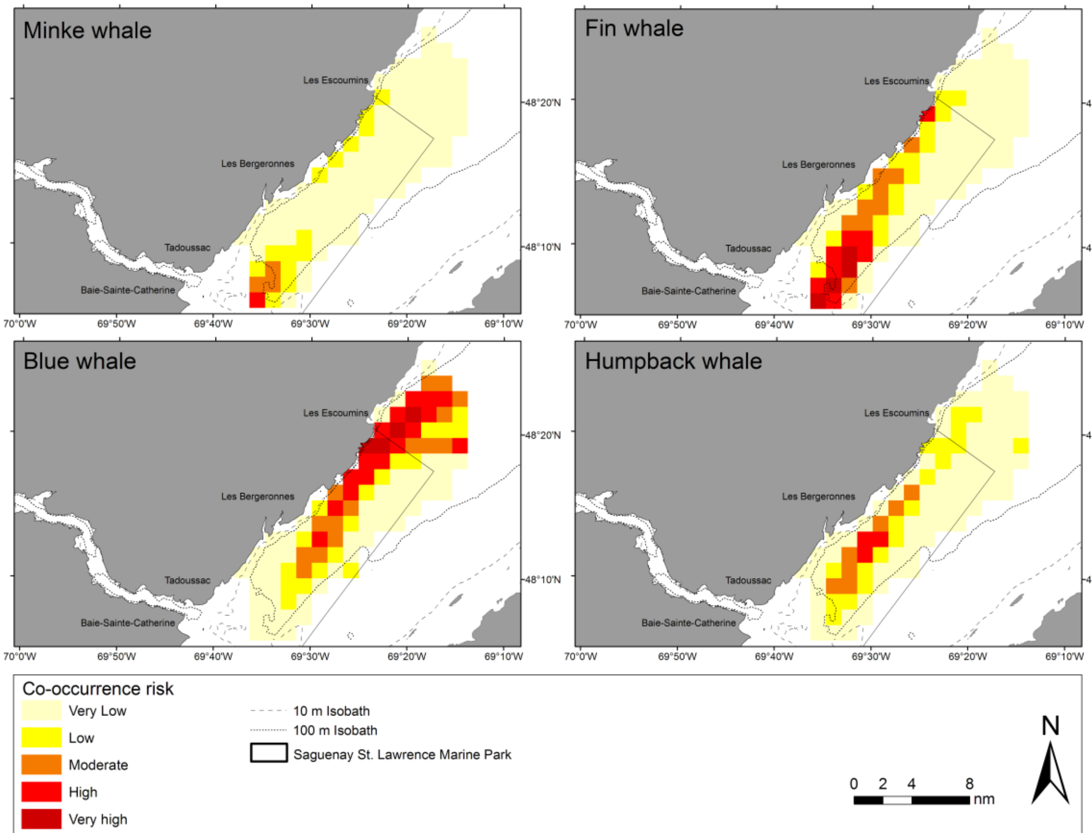


Figure 54. Characterisation of the degree of co-occurrence between baleen whale species and large ship traffic within the study area.

The overlay of the blue whale extrapolation model with the ship traffic intensity identified *moderate* to *very high* co-occurrence risk areas along a vast portion of the study area (Figure 55). The main risk areas are at the vicinity of Les Escoumins, as highlighted in the analysis restrained to the prediction grid extent, and along the 200 m isobaths along the southern cliff (Figure 55).

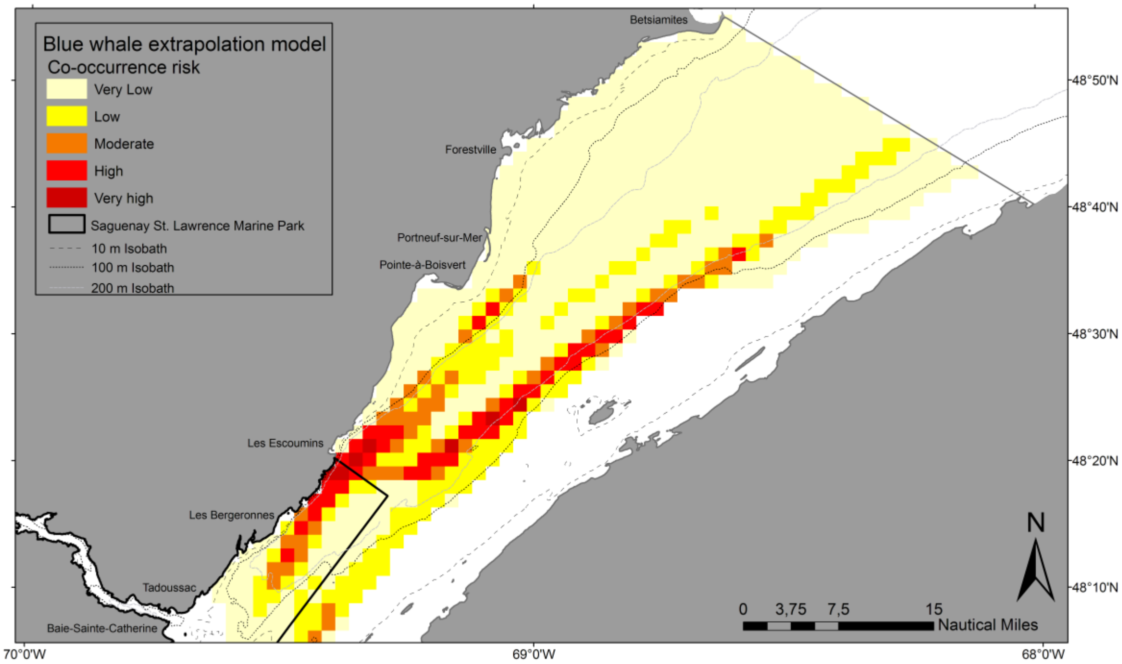


Figure 55. Predicted degree of co-occurrence between the blue whale and the large ships' traffic within the study area.

4.3.2 Management solutions

The speed reduction zone recently recommended by the working group on marine mammals and maritime traffic to reduce the collision risk between baleen whales and large ships in the study area encompasses almost the totality of the *high* and *very high* co-occurrence risk areas identified for minke and fin whales (Figure 56). Despite the protection to the coastal area used by the endangered blue whale, part of the *high* and *very high* co-occurrence risk areas identified for this species are outside the speed reduction zone and of the avoidance zone. The same was observed for humpback whales, for which only part of the main risk areas were within the cautionary zone.

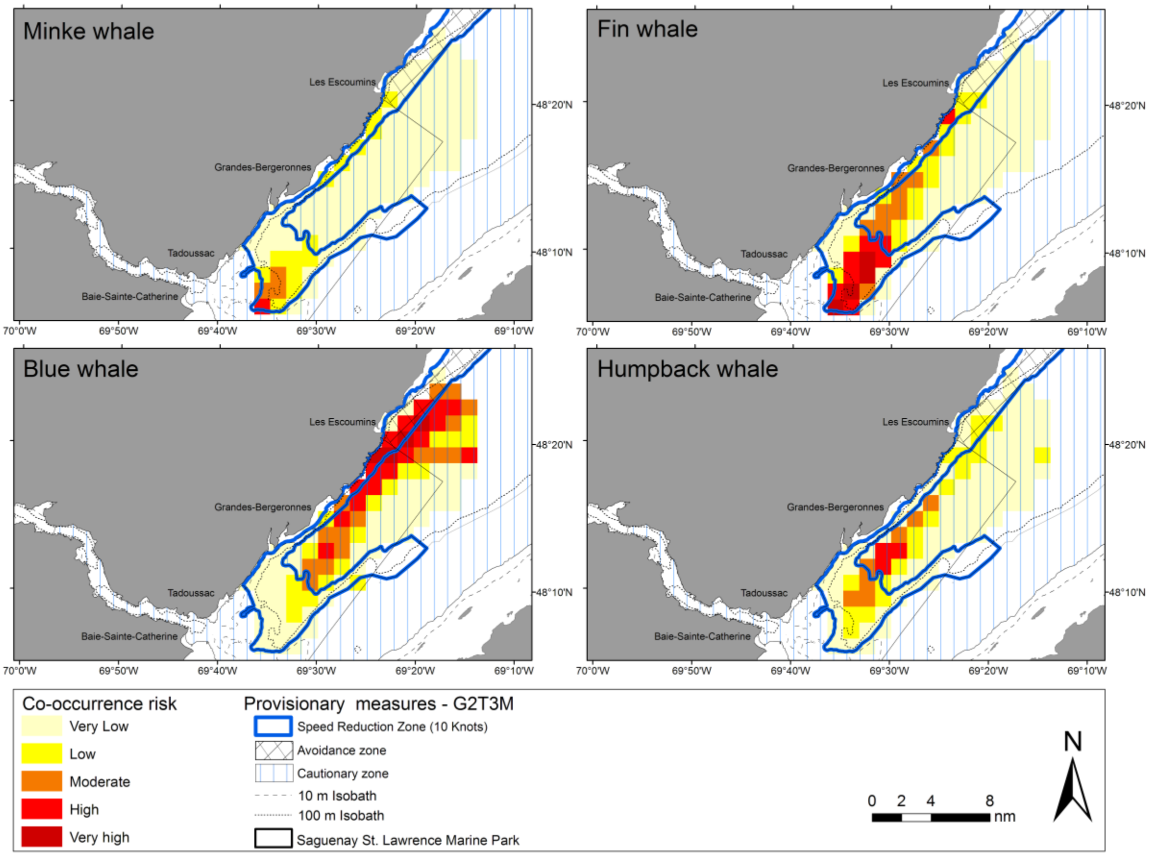


Figure 56. Overlay of the provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M) and the characterisation of the degree of co-occurrence between baleen whale species and large ship traffic within the marine portion of the study area.

A total of 71% of the *very high* co-occurrence risk areas identified in the analysis using the grouped SDM are within (at least partially) the speed reduction zone proposed by the G2T3M, while 50% of the *high* risk areas are within this zone. The speed reduction zone covers around 60% of the areas characterised as *high* and *very high* risk of co-occurrence with the grouped SDM of baleen whales (Figure 57). The cautionary zone was omitted in Figure 57 and Figure 58.

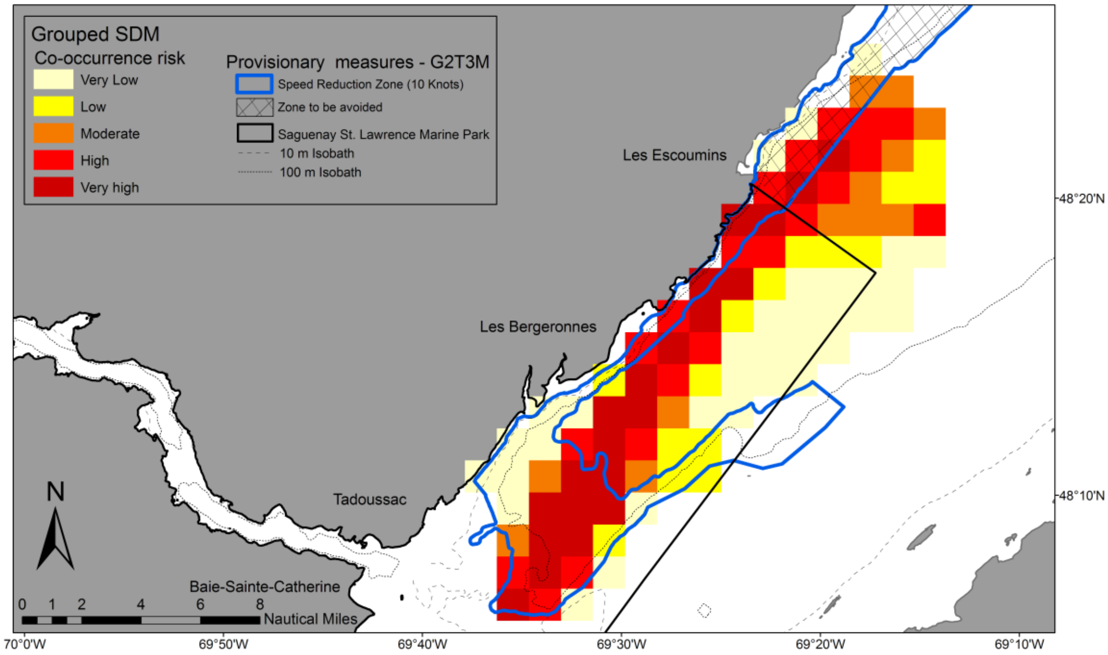


Figure 57. Overlay of the provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M) and the characterisation of the degree of co-occurrence between baleen whale species and large ship traffic within the study area.

In the vicinity of Les Escoumins, part of the co-occurrence risk areas is attributed to the configuration of the TSS (Figure 58). It is in this area that ships going down-stream modify their bearing to follow the TSS. Based on the results presented above, an adjustment to the TSS was suggested (Figure 59).The proposed adjustment keep the traffic in the same area (as within the SSLMP) for approximately 16 km, before modifying the bearing of the down-stream ships' to follow the TSS. In addition, the TSS was repositioned to avoid the 200 m depth contour, avoiding areas predicted as important habitats for the blue whale.

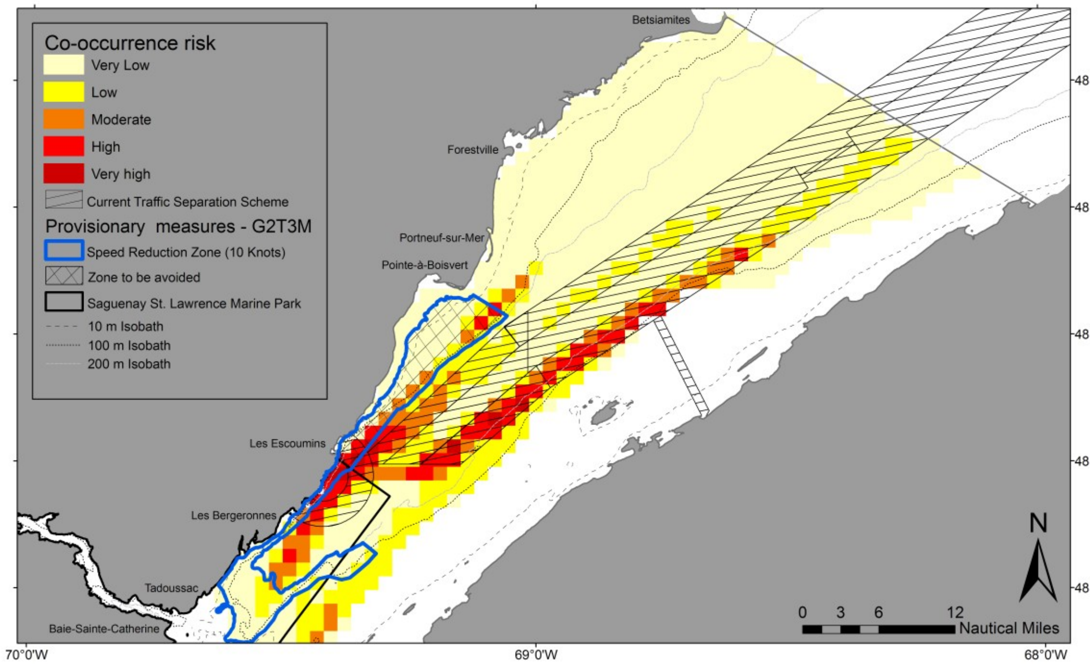


Figure 58. Overlay of the provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M), the degree of co-occurrence between baleen whale species' (grouped and extrapolation model) and large ship traffic, and the traffic separation scheme of the St. Lawrence River Estuary.

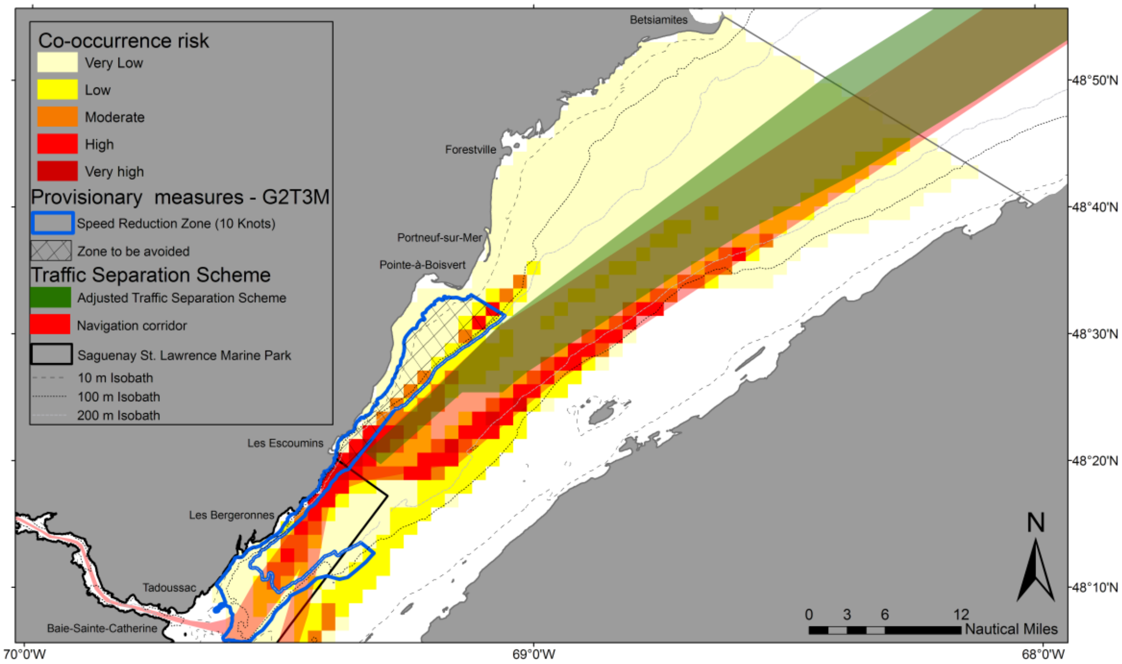


Figure 59. Overlay of the co-occurrence risk map, the provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M), the current navigation corridor and the proposed adjustment to reduce whale-boat co-occurence in the St. Lawrence River Estuary.

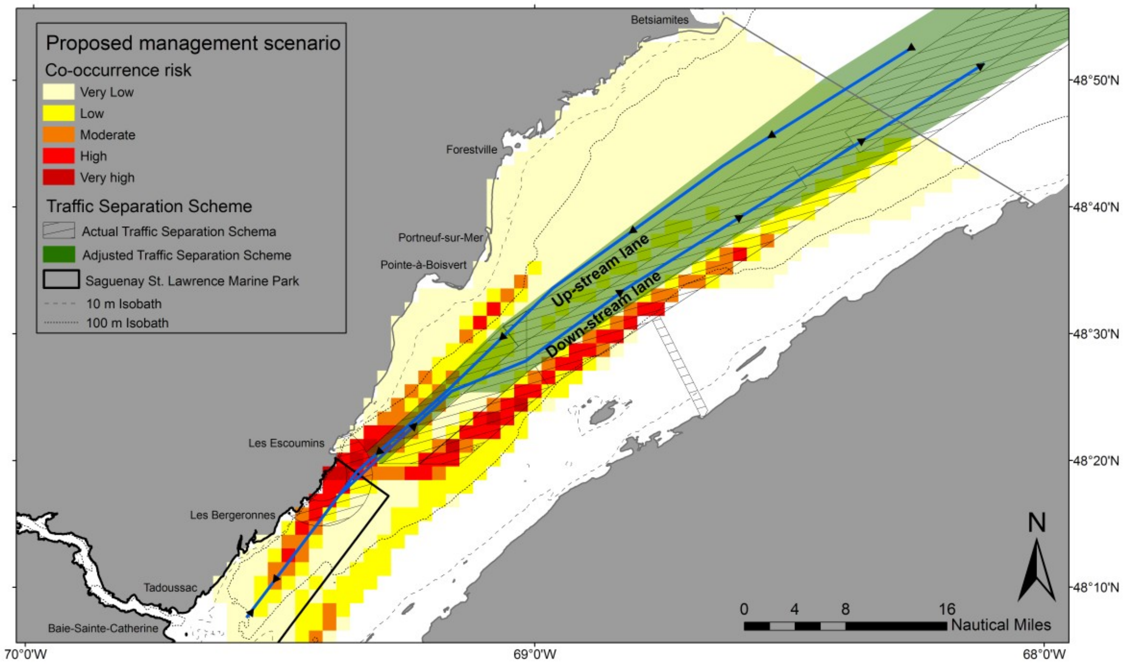


Figure 60. Overlay of the co-occurrence risk map and of the proposed adjustment to the current traffic separation scheme avoiding high density areas and the 200 m bathymetric contour intended to reduce whale-boat co-occurrence in the St. Lawrence River Estuary.

4. 4 Discussion

The impact of marine traffic on cetacean species is of growing concern. The direct impact is still to be quantified as most of the strikes are not reported. Most of the known data in this regard date only from the 1990s on (e.g. Laist *et al.* 2001; Panigada *et al.* 2006a; Ritter 2009; Ritter 2012). Most reported ship strikes with cetaceans occurred in the North Atlantic (Laist *et al.* 2001; Van Waerebeek and Leaper 2008; Ritter 2012). Panigada *et al.* (2006a) reported an increasing collision rate from 1 to 1.7 whales/year from the 1970s to the 1990s for fin whales in the Mediterranean. In addition, based on the analysis of 383 photo-identified fin whales, 9 (2.4%) had marks that were attributed to a ship impact. In the St. Lawrence, many whales present such marks, although the exact proportion of affected animals is unknown. Among the blue whales photo-identified in the area 16% bear scars that were likely to be caused by collisions with vessels (Ramp *et al.* 2006).

In 2007, the International Whaling Commission designated an *Ad hoc* committee to work specifically on the ship strikes issue (IWC 2009). Currently, an on-line form is available at the IWC website to report strikes incidents and several organisations worldwide are promoting it. Moreover, there is an increasing movement worldwide to find solutions to decrease collision risk (e.g. Kraus *et al.* 2005; IWC 2007; David *et al.* 2011; NOAA 2011), and reducing co-occurrence is amongst them.

Reducing co-occurrence requires an in depth knowledge of the cetacean species' distribution. In the SLRE, systematic data on cetacean distribution is available mainly within the marine portion of the SSLMP. The spatial density models (SDM), presented in the previous Chapter, constitute the first in-depth analysis of systematic data collected within the area. The extrapolation exercise was proposed to fulfill the lack of information in the area adjacent to the Marine Park, within the proposed SLEMPA. Although independent data confirmed model adequacy and the precautionary principle validates its utilisation in the present risk analysis, systematic surveys covering this area are required.

Combined, the SDMs and the extrapolation model allowed the cartography of the co-occurrence of whales and the large shipping industry over this portion of the territory. Once implemented, the measures recently proposed by the working group on marine mammals and maritime traffic have the potential to decrease the collision risk over 60% of the areas of very high and high co-occurrence identified here. It was demonstrated that the greatest rate of change in the probability of a lethal injury to a large whale occurs between vessel speeds of 8.6 and 15 knots where the probability of a lethal ship strike increases from 0.21 to 0.79 (Vanderlaan and Taggart 2007). By reducing speed to 10 knots within the proposed zone, which covers areas with a high density of baleen whales, the risk of lethal collision will be largely reduced (Laist *et al.* 2001).

Local measures to mitigate ship strike have been suggested and/or have been undertaken in different places. At the Glacier Bay National Park and Reserve (Alaska), a temporary speed limit of 13 knots during the humpback whale occurrence season was adopted (IWC 2007; Harris *et al.* 2012). The same speed limit was adopted in the Strait of Gibraltar from 2007 on, and a lane modification was also implemented (IWC 2007). To date, boats transiting within the SLRE have their speed limited to 25 knots while crossing the Saguenay–St. Lawrence Marine Park (SSLMP), and boats engaged in whale watching activities should limit their speed to 10 knots only while inside an observation zone / area (SOR/2002-76).

The adjustment to the TSS suggested here would complement the already discussed measures. The adjustment aims to enhance the protection of the endangered blue whale, a measure recommended as part of the species recovery strategy (Beauchamp *et al.* 2009). In California, different solutions have recently been implemented to struggle with the need to reduce ship and whale co-occurrences, with a main focus on blue whales (NOAA 2011). There, an adjustment of the TSS, aiming to avoid a portion of the shelf break was implemented. Modification of shipping routes has also been implemented to reduce the collision risk between commercial ships and the North Atlantic right whales, (Kraus *et al.* 2005; Merrick and Cole 2007; Vanderlaan *et al.* 2008), and was suggested in the Pelagos Sanctuary to protect fin whales habitats (Panigada *et al.* 2006b; David *et al.* 2011), and to improve humpback whale protection on a Brazilian breeding ground (Martins 2004) and in Panama (IWC 2012).

Management measures to reduce the effects of an intense marine traffic should also integrate measures to reduce noise production. Measures to create spatio-temporal restrictions of noise, also as part of Marine Protected Areas (MPAs) management plans, offer one of the most effective means to protect cetaceans and their habitat from the cumulative and synergistic effects of noise (Weilgart 2007) (Agardy *et al.* 2007). Indeed, including noise in marine spatial planning requires knowledge of noise levels on large spatial scales. The application of the method developed by Erbe *et al*. (2012) based on Automatic Identification System (AIS) data to derive large-scale noise maps is strongly encouraged as a next step in the management of the issue within the study area.

In the present Chapter, it was demonstrated the existence of an important overlap between baleen whales distribution and the ship lanes that cross the area. This is the first time that an integrated analysis aims to verify the degree of overlap between cetacean species and ship lanes within the SLRE. The adjustment of the TSS, here proposed might inspire stakeholders of the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* - G2T3M) to find a solution that meets the security rules determined by the concerned agencies (*e.g*. Transport Canada) while decreasing whales' exposure and enhancing their conservation in the area.

Chapter 5

Blue whales fine scale behavior and exposure to whale watching boats in the Saguenay-St. Lawrence Marine Park, Canada

5.1 Introduction

The blue whale (*Balaenoptera musculus*) is the biggest animal that has ever existed in the world. This cosmopolitan species has been evolving on the planet since the late Miocene. Population numbers worldwide were drastically reduced due to whaling and the remaining individuals are usually distributed in off shore areas, limiting research effort. They have one of the most critical conservation statuses amongst the large whales being considered as endangered globally (Reilly *et al.* 2008) and locally (Sears and Calambokidis 2002). Despite of that our knowledge of their behavior, ecology and vulnerability to human-induced threats still is largely deficient.

In the North Atlantic, the remaining animals are mainly distributed in Eastern Canadian waters, and the gulf and estuary of the St. Lawrence River comprise most of the species post-whaling sightings (Sergeant 1966; Mitchell *et al.* 1982; Sears *et al.* 1990; Sears and Calambokidis 2002). Important feeding aggregations found along the North Shore of the Province of Quebec at the Mingan / Anticosti Island region, off the Gaspé Peninsula, and into the St. Lawrence Estuary up to the Saguenay River have been monitored since the 1970s (Sears *et al.* 1990; Sears and Calambokidis 2002). Sightings have been reported from January to November with occurrences peaking from August to October (Sears *et al.* 1990; Sears and Calambokidis 2002). Robust abundance estimates are not available but to date around 400 different animals have been photographically identified since 1980s (Ramp *et al.* 2006). Within their feeding range, blue whales present a nomadic behavior (Mizroch *et al.* 1984; Sears *et al.* 1990) that is strongly related to the dynamics of formation and depletion of dense krill patches. This is translated by low residency periods within restricted areas encompassed by their home range. However, animals show high site fidelity, often returning to the same feeding spots (Sears *et al.* 1990).

The Saguenay-St. Lawrence Marine Park (SSLMP) was decreed in 1998 with the aim of improving the conservation of the habitat used by blue whales and the 12 other marine mammal species that frequent the region (PMSSL 1995). Four baleen whales (*B. musculus, B. physalus, B. acutorostrata and Megaptera novaeangliae*) are regular summer feeders and beluga whales (Delphinapterus leucas) and gray seals (*Halichoerus grypus*) are residents year-round (PMSSL 1995). Under the Ocean Act (1996), the Department of Fisheries and Oceans (DFO) of Canada has proposed the St.-Lawrence Estuary Marine Protected Area (SLEMPA) aiming to improve the conservation of the area surrounding the SSLMP. But to date the SLEMPA project is still in progress. Both MPAs are located downstream of the great lakes drainage basin concentrating high levels of toxic contaminants and are in the middle of the main navigation corridor of the Eastern Canadian Coast.

A recent study of the marine traffic in the area estimated 51 796 (CI± 11%) transits within the Marine Park annually, of which 25% correspond to the whale watching activity (Chion *et al.* 2009). The region is amongst the best places to experience whale watching in the world (Scarpaci *et al.* 2008) attracting more than one million visitors annually of which more than 250 000 take a boat trip (Gosselin 2009). At present, 59 boats hold permits to operate within the Park, among which 43 are dedicated exclusively to marine mammal observation, 10 are not in use and six are dedicated to other activities (*i.e.* sailing, diving) (PMSSL (2011). At the peak of the touristic season in 2007, a maximum of 171 whale watching trips were offered per day (estimate based on the number of operating boats and their published schedules) (C. Chion, personal communication).

It is now largely acknowledged that marine traffic poses threats to cetacean populations (Richardson *et al.* 1995; Laist *et al.* 2001; Weilgart 2007; Wright *et al.* 2007). Known effects range from indirect (e.g. noise pollution: Weilgart 2007) to direct (e.g. ship strikes: Laist *et al.* 2001; Berman-Kowalewski *et al.* 2010), from short to long-term (Glockner-Ferrari and Ferrari 1985; Salden 1988; Baker and Herman 1989; Lusseau 2003; Scheidat *et al.* 2004; Bejder *et al.* 2006; Williams and Ashe 2006; Morete *et al.* 2007; Stamation *et al.* 2010) and are consequence of different marine traffic categories (e.g., large vessels, ferry boats, whale watching: Waerebeek *et al.* 2007; Higham *et al.* 2009; Carrillo and Ritter 2010).

In the study area, it has been observed that blue whales alter their vocal behavior when exposed to loud ambient noise (Berchok *et al.* 2006). Authors suggested this reaction might improve the likelihood of being heard by their conspecifics due to the loud ambient noise of the St. Lawrence estuary. In addition, fifty-eight of the photo-identified animals of this population present ship-induced scars (Sears and Calambokidis 2002). Michaud and Giard (1998) have shown that sympatric fin whales alter their dive profiles as a consequence of interactions with whale watching boats, but the effects on blue whales have never been addressed. The Marine Park regulates the whale watching since 2002 (SOR/2002-76). The Marine Activity Regulations (SOR/2002-76) determines minimum approach distances depending on the boat type (commercial or private) and on species conservation status. Vessels shall not intentionally approach endangered species, as blue whales, and in the case of an unexpected encounter vessel should slowly move away and maintain a distance of at least 400m. However, compliance has never been systematically evaluated. Besides, contravention by non-compliant boats needs to be proven and a long verification process follows, making enforcement of the regulations difficult. In this context, the present work aimed to quantify blue whales’ exposure to whale watching activity, identify short-term effects of the boats’ presence on whales’ behavior and verify to which degree the regulations adopted by the Marine Park were respected.

5.2 Material and Methods

5.2.1 Study area and period of research

The study area comprises the marine portion of the St. Lawrence Estuary (Figure 61) which is located inside the SSLMP. Observations were conducted from two land-based stations located 9.5 km apart. Land-based station 1 (Les Bergeronnes) is 16.102 m above sea level and station 2 (*Mer et Monde* Camping) at 18.343 m. Both heights were measured with a Differential Global Positioning System (DGPS). Observation efforts were limited to a three nautical miles (1 nm = 1852 m) radius area to minimize instrument errors due to the low cliff height (Annexe 4). Effective data was collected inside two nm (3704 m). A 10 cm error in the instrument's height-above-sea-level at an approximately 15 m elevation provide accuracy of [-38, +39] m for targets at 5000 m, of [-17, +17] m for targets at 2500 m and of [-3, +4] m at 500 m (Würsig *et al.* 1991). It was assumed that the measurement of height-above-sea-level was accurate (DGPS measurement) and that for both land-based stations, which were higher than 15 m and target animals' were within two nm from the observation point it was assumed that all positions had errors smaller than 40 m. Observations were limited to good weather conditions (visibility over 8 km and wind below 16 knots). The study covered part of the core area of whale watching activity and the peak of the touristic season (Michaud *et al.* 2011). The research was conducted from late July to early September from 2008 to 2010.

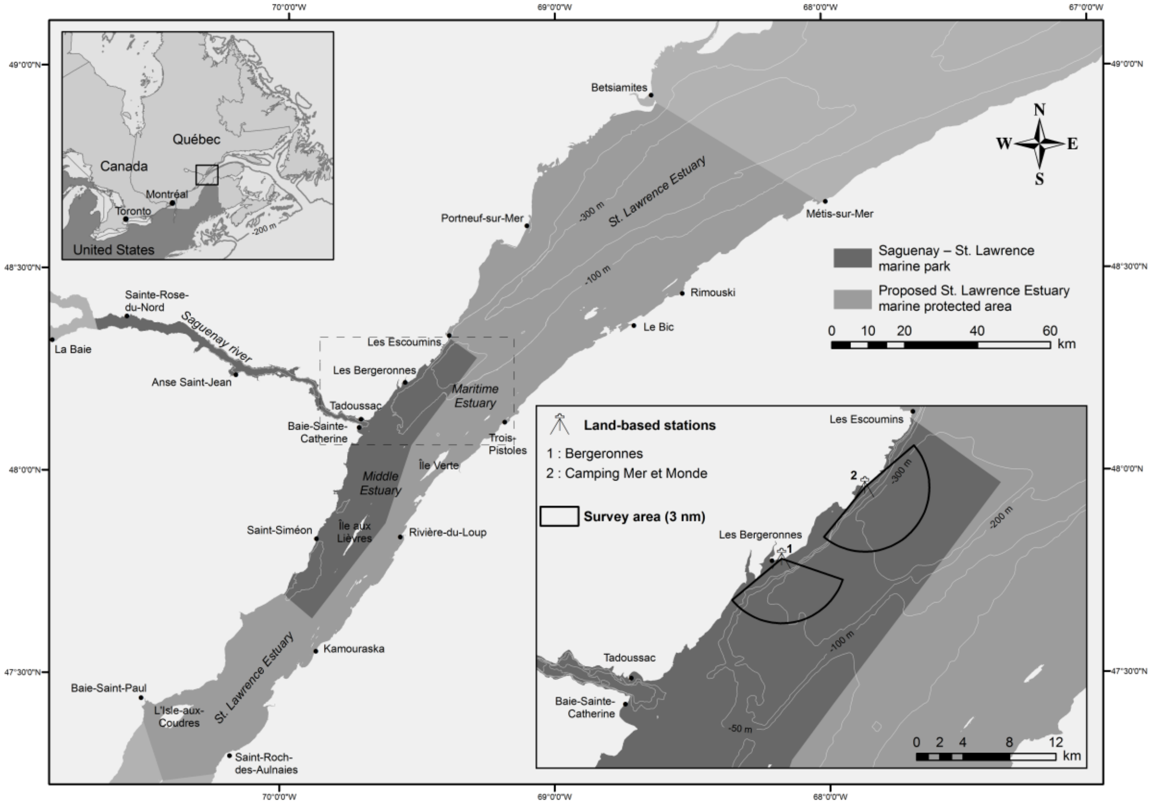


Figure 61. Boundaries of the Saguenay – St. Marine Park, the proposed St. Lawrence Estuary MPA and the land-based stations from which focal-animal observations of blue whales were conducted.

5.2.2 Marine Activity Regulations

The current Marine Activity Regulations (SOR/2002-76) determines minimum approach distances depending on the boat type (commercial or private) and on species conservation status. The closest distance of approach for commercial boats observing a non-endangered species is 100 m, and for private boats it is 200 m. Vessels must respect a 400 m distance with endangered species (blue and beluga whales). Vessels shall not intentionally approach endangered species and in the case of an unexpected encounter at less than 400 m the regulation states: “the operator of the vessel shall reduce the speed of the vessel to a speed not greater than the minimum speed required to manoeuvre the vessel” (SOR/2002-76, 20th paragraph).

5.2.3 Data collection protocol

Blue whales were tracked from the coast using a total station (Leica TC805L and TCR1103). Individual whale movement data were collected following a focal-follow protocol and continuous sampling method, both of which are best applied to follow single or paired animals which were the main focus of this study (Altmann 1974; Mann 1999). Observations were systematically carried out by two observers, one using the total station and another assisting with a pair of binoculars (7x50 Bushnell). While tracking the focal-animal, observers attempted to position all blows while recording all observed behaviors at a second precision. Table 16 describes the observed behaviors and adopted definitions.

Boats within a 1 km radius of the focal-animal were considered to have an effect on animal’s behavior, and these instances were defined as whale – boat interaction. All boats within the binocular observer’s field of view were positioned at least twice using the total station and boats within 1 km radius of the focal-animal were positioned before and after the focal-animal surface interval (Table 17) and whenever they moved actively. Boats were classified according to their types, sizes and main activity as: whale watching zodiac, big whale watching boat, kayak, private boat and research boat. Only *ad libitum* information on other marine mammals was collected.

Focal-animals were chosen after systematically scanning the observation area. Choice was based on distance from shore and group composition, preference being given to single individuals. Individual identification during tracking was regularly verified using distinctive characteristics of the focal-animal (i.e., scars, natural markings, shape of dorsal fin). Each focal-animal was tracked for at least 30 minutes, which in the case of blue whales corresponds to at least two surface intervals (SI) under observation. Observations were terminated if the identity of the focal-animal was not ascertained, if animals moved beyond the study area limit or weather conditions became unfavorable.

A team of three persons was present at each site: the two observers mentioned above (total station operator and binocular observer) and a note taker. The total station operator was responsible for taking all the positions by recording a vertical and a horizontal angle that corresponded to the target position and to dictate all observed behaviors to the note recorder. Coordinates were registered into the total station memory and were downloaded every day (see whole field work protocol at Annexe 2). In order to insure maximum consistency, the total station operator was always the same. At the same time, the note recorder registered time (at the second precision) of all observed behaviors and the position code (when available). The binocular observer was equipped with a 7x50 Bushnell and his/her function was to assure that the total station operator did not miss any behaviors of the focal-animal. This was necessary due to the total station magnification (30 times), as animals moving too fast or with long dives might return to the surface outside the total station's field of view. The binocular observer also would warn the team of the arrival of boats and other marine mammals in the observation area.

Each time boats were positioned, their behavior was classified as approaching or leaving the focal-animal, accompanied by a visual classification of their movement pattern: moving slowly (boat moving while producing some white caps), and moving fast (boat moving at higher speeds and producing a lot of white caps and spray in the water) and still (boat moving very slowly with no white caps around it characteristic of a boat in observation of a cetacean).

Collected data were examined at the end of each observation day in order to determine data quality. For the purpose of this analysis only focal-follows with complete and reliable observations of animal's breathing rates (based on note recorder's notes), conducted within 2nm from the observation site and without gaps in the observation sequence were kept.

Cyclopes® (Kniest 2004) was used to transform vertical and horizontal angles measured by the total station into latitude and longitude by taking local tide height variation (transcribed from official Canadian charts) into account. Under request by the authors, the software was modified to allow the calculation of the distance between the focal-animal and other surrounding targets. By using this option, all boats' positions acquired inside the time interval of [-3; +3] minutes from an animal's true position were interpolated and used to calculate distances between the animal and all boats within a 1 km radius. This was done systematically for each target position recorded for each focal-follow.

5.2.4 Behaviour

Focal-animals' activity was determined *a posteriori* based on observed behaviour events (Table 16) and movement pattern. Directedness and deviation index were calculated for each animal according to Williams *et al.* (2002). Animals with low directedness of movement (< 70) performing pronounced arching final dives, circling or following "J" shaped or half circle tracks while at the surface (Lynas 1994) were considered to be foraging. Animals with a high directedness (> 70) of movement during the whole trajectory were considered to be travelling.

Table 16. Adopted ethogram for the land-based observations of blue whales.

Behavior	Definition
Arching	Pronounced arching of the peduncle typically observed before a true dive
Caudal curl	The tightly arched back of the whale is held or raised in an arch above the water, with little rolling movement, while the whale continues to move forward (Mitchel *et al.* 1982).
Fluke-up dive	The fluke is completely (>45°) or partially raised above the water typically preceding a true dive.
Surface-swimming	Animal moves forward without completely submerging its body in between consecutive blows.
"J" surface geometry, arcing or circling	A blow series through which the whale progressively changes its direction of travel from blow to blow, thus following a J or L shaped swimming path, resulting in a semi-circular or circular arc on the water surface.

5.2.5 Breathing pattern

Following Dorsey *et al.* (1989), breathing patterns of the tracked whales were characterized with a suite of five variables measured using each surface-dive cycle as a sample unit: surface interval (SI), dive interval (DI), number of blows per surfacing (NB), blow interval (BI) and blow rate (BR). A sixth variable, time near surface (TNS), was averaged over the duration of a complete focal-follow (Dorsey *et al.* 1989). These variables are defined at the Table 17.

An analysis of variance (Tukey's HSD - Honestly Significant Difference) was performed in order to see if BR was similar among the observed animals. Animals with a similar blow rate were used in order to test the effect of boats' presence on blue whales breathing pattern. For that, a Spearman correlation test was performed between exposure duration (percentage of SIs in the presence of boats) and blow rate's coefficient of variation. A p-value of <0.05 was used for significance. Analyses were run with R 2.10.1 (R Development Core Team 2009).

Table 17. Variables used to described blue whales' breathing pattern and adopted definitions

Variable	Definition
Surface Interval (SI)	The amount of time between the first and the last blow of sequence before a longer dive (SI_n, SI_{n+1}, SI_{n+2}, …)
Dive Interval (DI)	The elapse of time longer than 60sec during which the animal wa below the surface, or the time between the last blow of sequence, and the first of the following one. (D_n, D_{n+1}, D_{n+2}, …)
Number of Blows (NB)	Number of blows during the surface interval (SI)
Blow Interval (BI)	Elapse time between consecutive blows; if greater than 60sec was considered as a true dive
Time near surface (TNS)	Sum of surface intervals divided by total observation time
Blow rate	Number of blows (NB) during the surface interval *n* divided b the surface interval' duration (SI) plus the previous dive interva duration. Expressed in NB $hour^{-1}$. $BR= NB_n/(SI_n + DI_n)$

5.2.6 Exposure to boats

Exposure to boats was calculated for each individual and for the whole observation period. As boats usually left the observation area after a true dive, only the surface interval was considered to calculated exposure. All whale - boat interactions occurred on an opportunistic basis, meaning that observers were not in communication with boats crossing the observation area and did not interfere with boat behavior.

Exposure was measured by boat type and distance category. Based on the current whale watching regulations, five distance categories were adopted: <1000 m (or total exposure), >400 m, <400 m, 100-200 m, and <100 m. The value assigned to any distance category represents the percentage of SI in which boats occurred within this distance category for at least a blow. This value will also be referred as percent of time or percent of observation time.

5.2.7 Boats compliance to current whale watching regulations

Data were inspected to determine if encounters between blue whales and boats occurred at distances less than 400 m. In the case of a negative answer, it was verified if the boat was still (observing the focal-animal), or if it was approaching or leaving it. And, in the case of encounters within a 400 m radius, it was verified if boats respected the distance specified for commercial (100 m) or private boats (200 m) and non-endangered cetacean species.

The regulation states that captains should not place the vessel within the path of a cetacean (SOR/2002-76). However, the area (or angle) to be avoided is not clearly stated. Data were examined to detect if boats were using the forehead angle in front of the focal-animal's path to approach them.

5.3 Results

At the peak of blue whales occurrence from 2008 to 2010, 307 hours of land-based observations were conducted over 80 days. A total of 14 blue whales were tracked for a total of 1629.65 min. Of these, 8 focal-follows totaling 870 min (108.8 min ± 60.9) of observation were kept for analyses: one from 2008, 7 from 2009 and none from 2010 (whales were absent from the study area). Two individual focal-follows (240809L and 270809A) were confirmed to be of the same animal, a whale named Crinkle (Mingan Island Cetacean Study – MICS catalogue), which was observed on two different days confirming a minimum residency time of four days.

5.3.1 Behaviour

Observed animals concentrated their activities within one nautical mile from the north shore, with observed distances varying from 200 to 1680 m from the coastline (969 m ±321) (Table 18). The distance between foraging dives averaged 297 m (±204; n = 60) and the true dives of the traveling animal were 1115 m (±143; n = 2) apart.

All except one of the tracked whales, whose directedness was of 99.2 (Table 18), were considered to be foraging and no changes in activity state were observed within any of the individual focal-follows. The only animal considered to be traveling (focal-follow 270809A) was indeed leaving the study area (Figure 62).

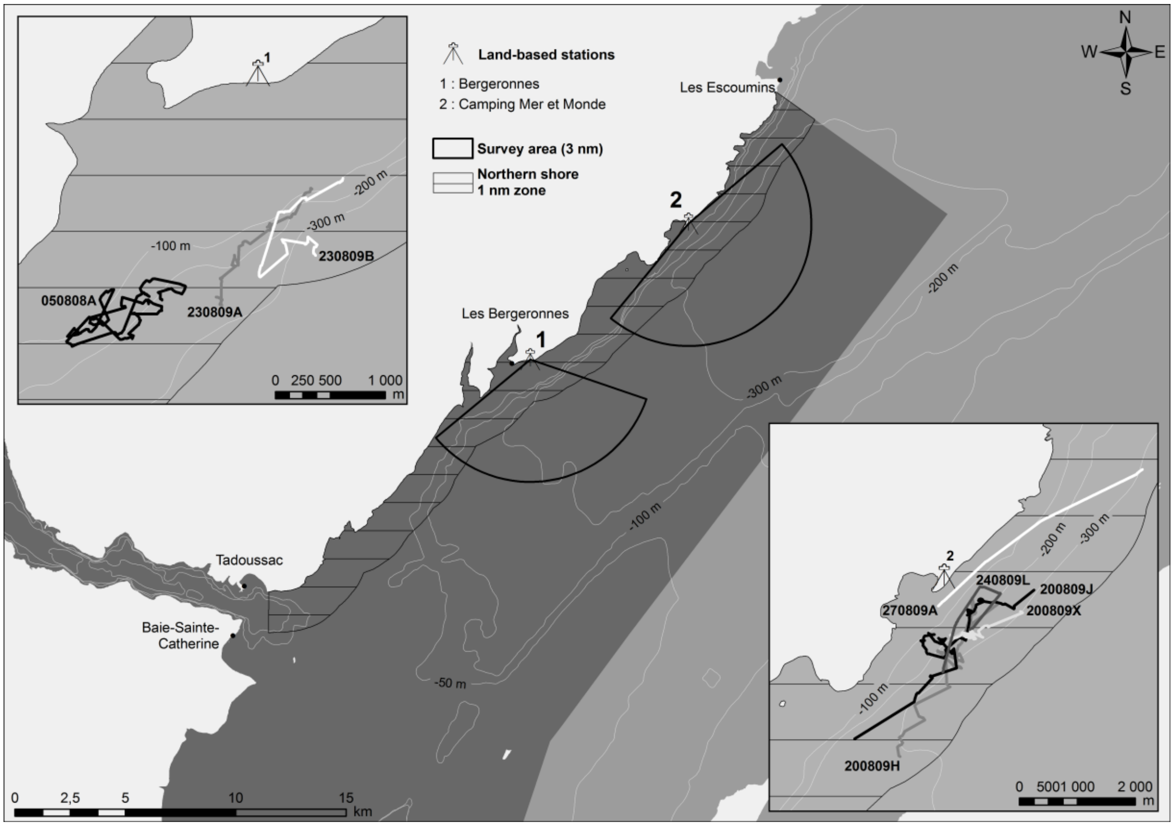


Figure 62. Individual blue whales' tracks obtained from the land-based stations showing fine-scale movement patterns (all valid fixes) within the northern shore one nautical mile zone.

Table 18. Summary of *Balaenoptera musculus'* breathing and movement parameters (±SD) of the individual focal-follows conducted from two land-based stations located inside the Saguenay-St. Lawrence Marine Park in two consecutive feeding seasons (2008 and 2009) (**µ** : mean; DLB: distance to land-based station – mean (min;max); DCoast: distance to the nearest costline mean (min;max)).

ID	**050908A**	**200809H**	**200809J**	**200809X**	**230809A**	**230809B**	**240809L**	**270809A**
Duration (h)	2.7	2.6	3.39	1.48	1.7	1.5	0.61	0.53
NSI	18	18	19	9	9	7	5	4
NSI with boats	9	18	19	4	7	5	0	4
µ SI (min)	2.7 (±0.6)	1.7 (±0.5)	2.0 (±0.5)	2.1 (±0.3)	1.9 (±0.2)	1.9 (±0.6)	1.1 (±0.2)	1 (±0.5)
% TNS	29.7	19.9	19	21.7	16.6	14.5	14.8	13.1
µ NB / SI	10.1 (±1.7)	9.8 (±2.1)	9.5 (±3.0)	11.1 (±1.3)	10.0 (±1.8)	10.4 (±2.9)	4.4 (±0.9)	4 (±1.4)
µ BI (s)	17.8 (±2)	11.7 (±1.4)	13.4 (±1.5)	12.8 (±1.2)	12.8 (±2.1)	11.8 (±0.8)	19.9 (6.1)	20.6 (±1.7)
N dives	17	17	18	8	8	6	4	3
µ DI (min)	6.8 (±1.2)	7.4 (±1.9)	8.7 (±1.1)	8.7 (±0.7)	10.6 (±1.3)	12.8 (±2.2)	7.7 (±1.2)	9.2 (±2.7)
µ BR (NB/h)	64.1 (±6.0)	68.1 (±26.1)	59.0 (±11.1)	61.5 (±5.2)	47.5 (±9.1)	44.3 (±5.8)	32.6 (±2.8)	22.9 (±2.6)
µ BR	3.8 (±0.5)	5.8 (±0.7)	5.1 (±0.6)	5.2 (±0.5)	5.3 (±0.6)	5.5 (±0.8)	4.2 (±0.9)	4.1 (±0.6)
Directedness Index	26.1	47.7	52.5	49.9	61.9	31.5	30.7	99.2
Deviation Index	46.7	34.1	34.1	43.4	68.2	54.4	29.6	10.4
Track length (m)	7546	3690	4830	2565	2134	2381	2831	4271
DLB (m)	2395 (2011; 2854)	1413 (548; 3110)	1100 (614; 3118)	1045 (920; 1448)	1552 (1113; 2101)	1459 (1169; 1818)	905 (616; 1551)	1874 (316; 3928)
DCoast (m)	1010 (741; 1312)	1010 (504; 1446)	781 (482; 1230)	968 (790; 1293)	1387 (1015; 1680)	1381(1051; 1751)	729 (499; 1049)	682 (200; 1575)

5.3.2 Breathing pattern

Breathing parameters were estimated for all individual focal-follows (Table 18). The average time spent near the surface was 18.5% (± 5) and ranged from 13.1% for the traveling individual to 29.7%. Mean individual duration of SI ranged from 1 to 2.7 min, again with the minimum value recorded for the traveling animal. The average for all animals was 2 min (±0.7). Average true dive duration ranged from 6.8 to 12.8 min, with a general mean of 8.5 min (±2.2).

Blow rate varied among individuals (Figure 63) and an analysis of variance rejected the null hypothesis of homogeneity of variances among the individuals (Tukey's HSD, F = 17.151, p = 0.05). All animals considered to be foraging were statistically different from the traveling animal, with the exception of the focal-follow 240809L, which was of the same animal.

A positive correlation (0.73 - Spearman rho = 0.9, $p < 0.05$) was observed between the coefficient of variance of the blow rate and the duration of whale – boat interactions, demonstrating an effect of prolonged exposure on blue whales' breathing patterns. The traveling animal was excluded from this analysis based on the analysis of variance.

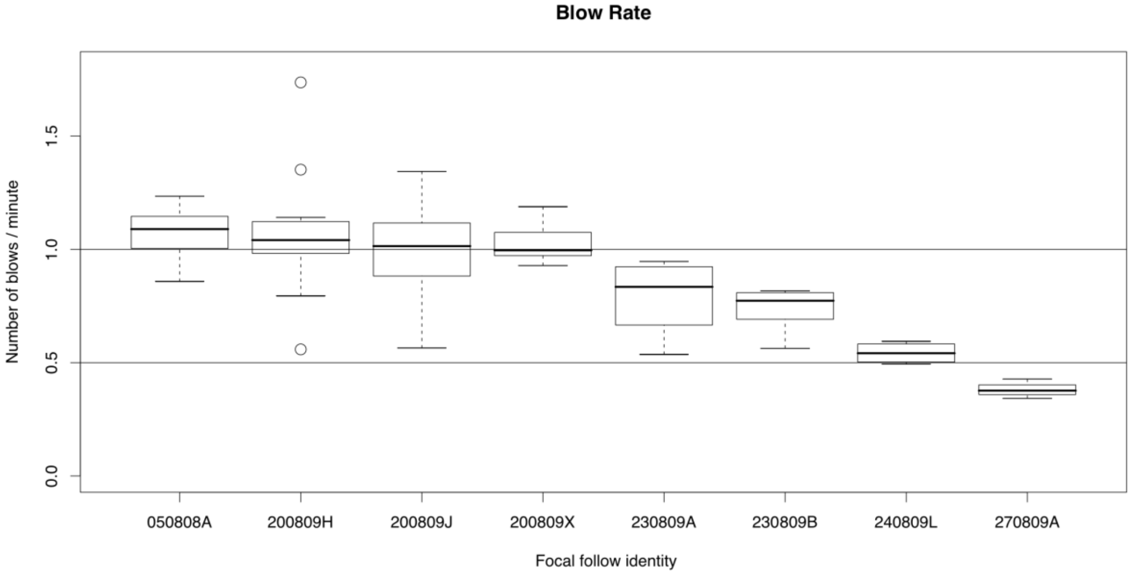
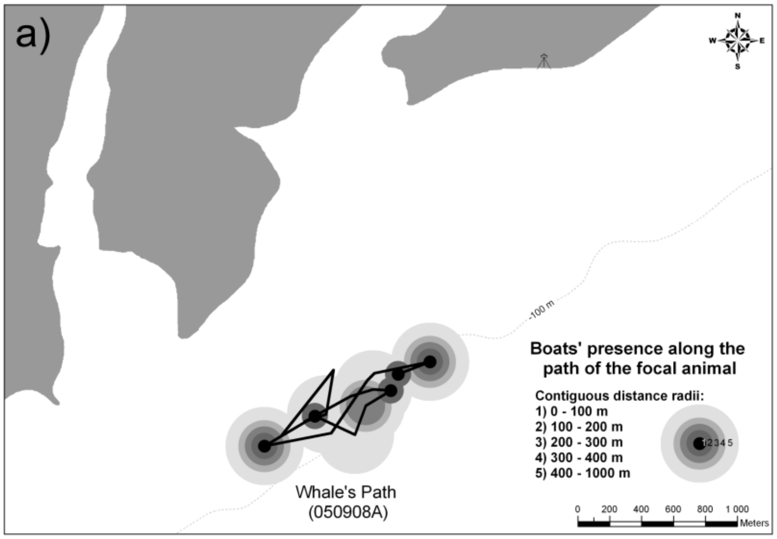
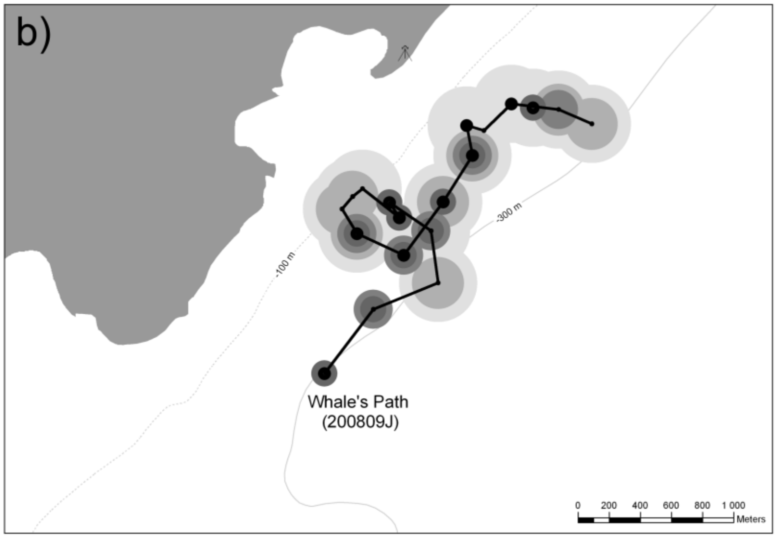


Figure 63. Blow rate for each observed blue whale showing individual differences. Animals exposed for longer periods showed a greater blow rate variance (0.73 - Spearman rho = 0.9, $p < 0.05$).

5.3.3 Exposure to boats

Whale – boat interaction occurred in all except one of the eight focal-follows, and corresponds to 74% of the SI analyzed (n = 89). Three focal-animals were exposed to boats 100% of the observation time and for the other focal-animals' exposure ranged from 44 to 71%. Consecutive exposure (at least one boat consecutively within a radius of 1 km) ranged from 2 to 19 SIs. The maximum number of boats by SI was of 14, and at this instance they were all commercial zodiacs. The average number of boats in whale - boat interaction per SI was 2.3 (± 2.7). Figure 64 illustrates exposure along the path of three different focal-animals.


a)
N
W
E
S
-100 m
Boats' presence along the path of the focal animal
Contiguous distance radii:
1) 0 - 100 m
2) 100 - 200 m
3) 200 - 300 m
4) 300 - 400 m
5) 400 - 1000 m
1 2 3 4 5
Whale's Path (050908A)
0 200 400 600 800 1 000
Meters


b)
-100 m
-300 m
Whale's Path (200809J)
0 200 400 600 800 1 000
Meters

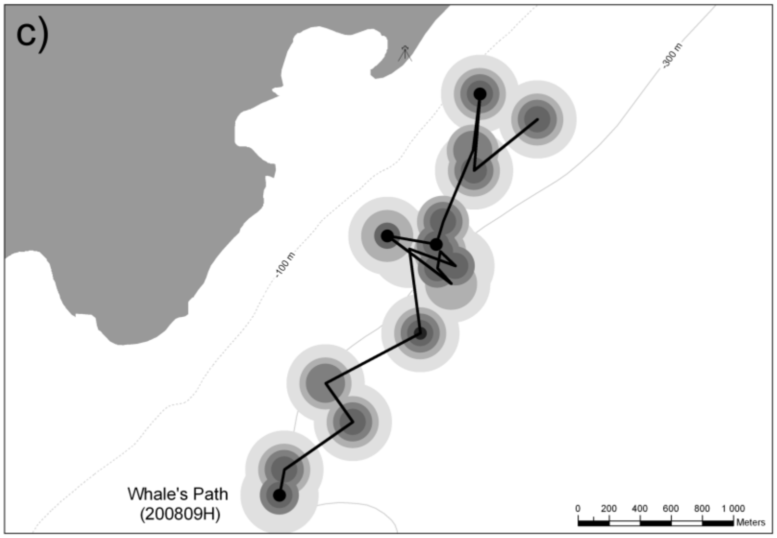

c)
-100 m
-300 m
Whale's Path (200809H)
0 200 400 600 800 1 000
Meters

Figure 64. Simplified track (only true dive positions) of three focal animals showing exposure to boats (presence within distance categories)and lack of compliance (boats within 400 m): a) individual followed the 5th September 2008 (050808A) from Bergeronnes (2.7 hours) – some surface periods without boats in between others in boats' presence and with boats within 100 m in 5 surface intervals; b) individual followed the 20th August 2009 (200809J) from *Mer et Monde* (3.39 hours) – accompanied by boats during the whole observation period and with boats within 100 m in 10 surface intervals; c) individual followed the 20th August 2009 (200809H) from *Mer et Monde* (2.6 hours) - accompanied by boats during the whole observation period and with boats within 100 m in 5 surface intervals.

Five boat categories were recorded in interaction with blue whales along the studied period: commercial zodiacs (from now on referred as zodiacs), kayaks (which included private and guided commercial trips), private boats (which included zodiac and sail boats – sailing or not), research boats and a cargo boat (only one occurrence at > 900m). Large whale watching boats (*i.e.*, boats having a capacity of more than 48 people) were not observed within 1 km of blue whales in the present study. Whales were exposed to zodiacs 60.7% of the total observation time, to private boats 22.5%, and to kayaks and research boats 20.2% (each) (Figure 65). The seven focal-follows in which whale – boat interaction was observed were approached by zodiacs, while four of them were also approached by private boats, 3 of them by research boats, and 2 of them by kayaks.

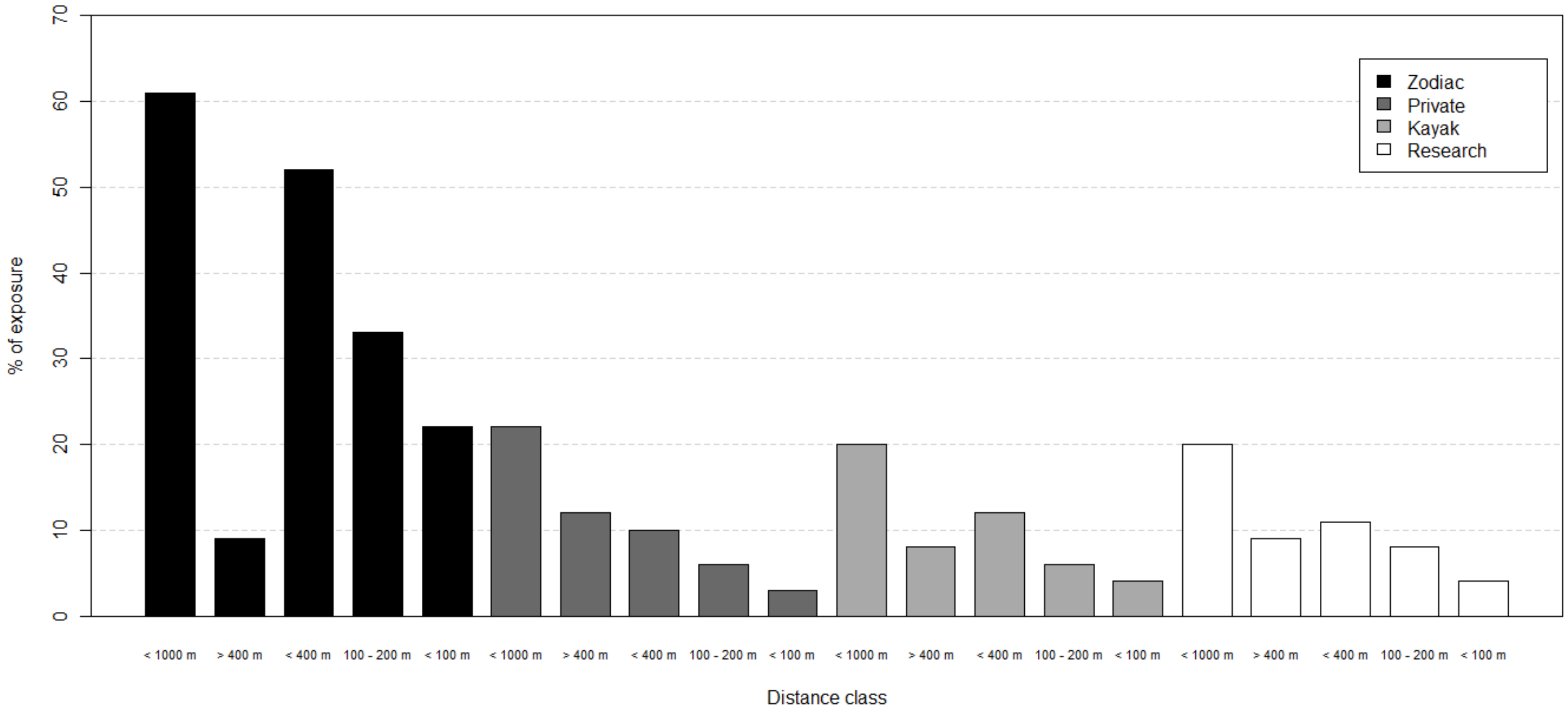
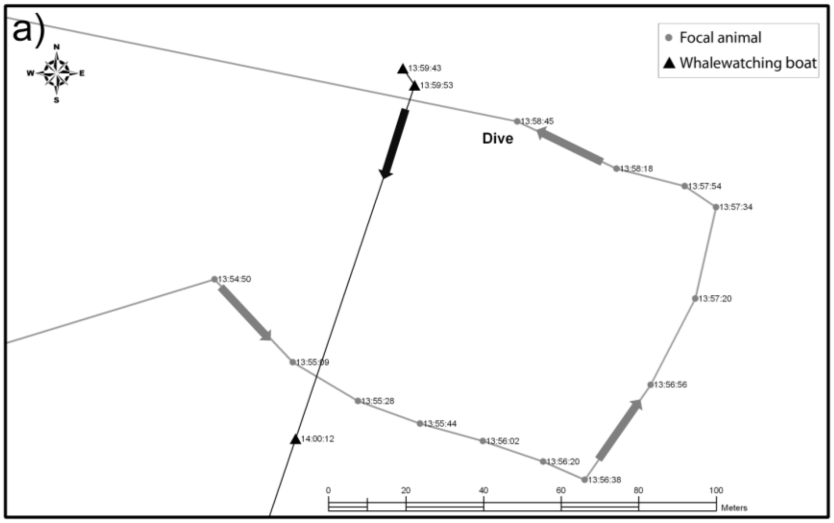


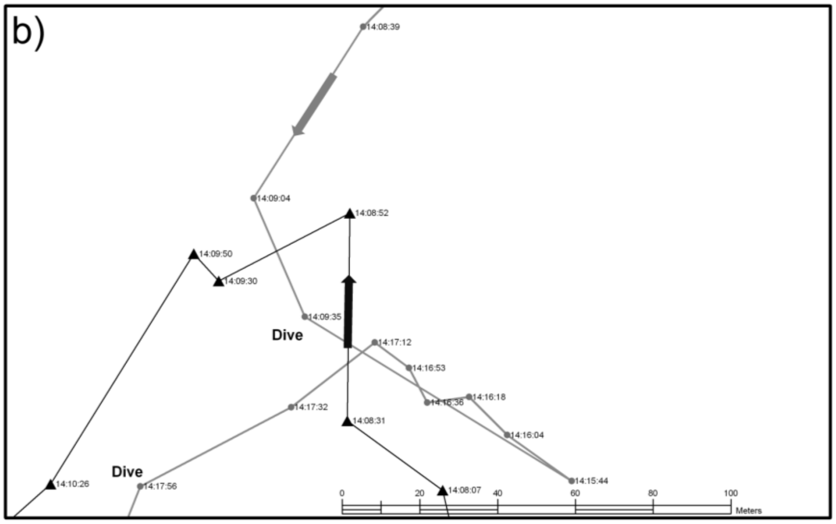
Figure 65. General exposure of blue whales observed at the Saguenay–St. Lawrence Marine Park by boat category and distance class. Compliant boats would be beyond 400 m of the focal animals.

5.3.4 Boats compliance to current whale watching regulations

Zodiacs were observed within 400 m of blue whales 51.7% of the total surface intervals. They were between a 200 and 100 m 32.6% of the SIs and within 100 m 22.5% of the SIs. Kayaks, private and research boats were within 400 m 12.4%, 10.1%, and 11.2% of the SIs, respectively, and were within 100 m less than 5% of the SIs (4.5%, 3.4% and 4.5%, respectively).

In only 9% of the total SI observed zodiacs kept beyond the regulated 400 m distance of blue whales, however, in all of these cases, the zodiacs were approaching or leaving the focal-animal, or were observing another marine mammal species in close proximity. While observing the focal-animal, zodiacs were inside the 400 m exclusion zone specified by Marine Park regulations 100% of the time. Additionally, some boats were observed approaching the focal-animal using the forehead angle of the animal's path as exemplified by Figure 66.


a)
N
W
E
S
● Focal animal
▲ Whalewatching boat
13:59:43
13:59:53
13:58:45
Dive
13:58:18
13:57:54
13:57:34
13:57:20
13:56:56
13:56:38
13:56:20
13:56:02
13:55:44
13:55:28
13:55:09
13:54:50
14:00:12
0
20
40
60
80
100
Meters


b)
14:08:39
14:09:04
14:08:52
14:09:50
14:09:30
14:09:35
Dive
14:17:12
14:16:53
14:16:36
14:16:18
14:16:04
14:17:32
14:08:31
14:15:44
Dive
14:17:56
14:10:26
14:08:07
0
20
40
60
80
100
Meters

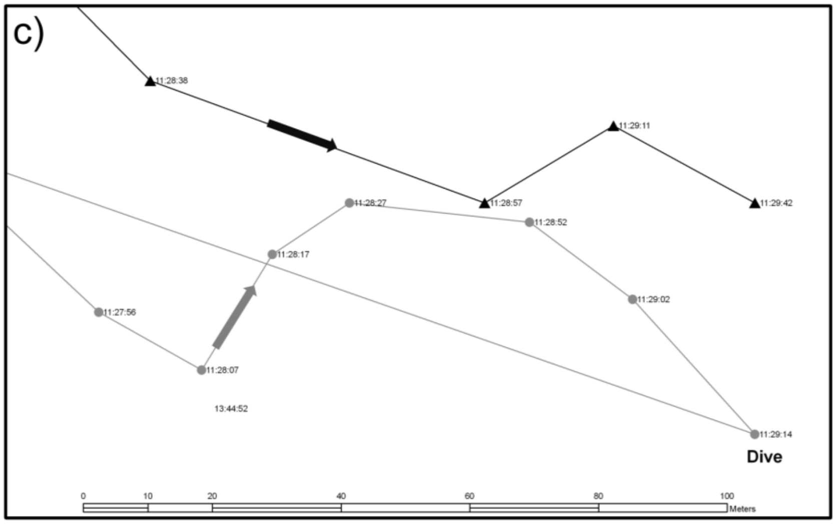

c)
11:28:38
11:29:11
11:28:57
11:29:42
11:28:27
11:28:52
11:28:17
11:29:02
11:27:56
11:28:07
13:44:52
11:29:14
Dive
0
10
20
40
60
80
100
Meters

Figure 66 Fine scale movement of blue whales and whale watching boats: a) “J” surface geometry characteristic of foraging blue whales and a whale watching boat approaching it (050908A) using the forehead angle; b) another whale watching boat actively approaching the focal animal 200809H within 100 m and using the forehead angle; c) another active approach within 100 m of the focal animal (200809H).

5.4 Discussion

The blue whale population of eastern Canada is recovering from the hunting period in an environment where human activities are well established and present multiple threats. Canada’s recovery team seeks to attain a population of 1000 mature individuals in order to revise their COSEWIC status from “endangered” to “not at risk” (Beauchamp *et al.* 2009). In order to achieve that it is a priority to decrease the species exposure to all activities that may harm the species recovery.

The studies here presented include the first study of blue whales from a land-based observation site. Land-based studies present the advantage of being completely non-intrusive and allow the description of animals’ movement patterns and of interactions with other targets (conspecific, heterospecific, and human activities) at the finest spatial scale. Gathered results improved our knowledge of the species fine scale behaviour and highlighted the need to enforce whale watching regulations within the Canadian Economic Exclusive Zone to decrease the species exposure to the activity.

5.4.1 Behavior

Blue whales’ occurrence and residency pattern within the SSLMP is highly variable intra- and inter-season. Understanding the factors governing the dynamics and availability of dense krill patches in the estuary is essential to understand the species habitat use pattern. Due to their high energetic demands blue whales’ displacements are guided by the availability of dense krill patches (e.g. Croll *et al.* 1998; Fiedler *et al.* 1998; Goldbogen *et* *al.* 2011) and they may be able to identify oceanographic processes that enhance prey aggregation from a certain distance (Croll *et al.* 2005). In addition, long distance communication may play an important role here, preventing animals from making unnecessary incursions into the study area. In the present study, we recorded the highest occurrence of blue whales during the new moon of August 2009. The stronger tidal variations during this moon phase are correlated with strong upwelling events in the area, but the factors governing local prey availability are still to be understood (MPO 2012). Blue whales are usually associated with upwelling systems or frontal areas (Croll *et al.* 1998; Fiedler *et al.* 1998; Palacios 1999; Hucke-Gaete *et al.* 2004; Branch *et al.* 2007; Gill *et al.* 2010; Doniol-Valcroze *et al.* 2011) and show preference for steep slopes (e.g. Croll *et al.* 1998; Branch *et al.* 2007). The estuarine circulation favors the aggregation of zooplankton around the abrupt slopes of the submarine canyon and at the Laurentian Channel's head (Simard and Lavoie 1999). Individuals tracked in the present study concentrated their activity within one nautical mile from the shoreline, which encompasses the northern cliff of the St. Lawrence estuary's submarine canyon. The average distance between foraging dives (296.9m ±203.7) was smaller than that recorded by Acevedo-Gutiérrez *et al.* (2002) in the North Pacific where the average was of 525.4 (±144.98m). This may reflect the patchy prey distribution in the estuary, also well illustrated by the focal-follow conducted in September 2008 (050908A) during which the whale was foraging within an area of approximately 1200 m by 500 m for more than three hours.

5.4.2 Breathing pattern

Information on blue whales' breathing parameters in the current literature is scarce. Among others, it can be used to correct visual abundance estimates by integrating animals' availability near the surface (e.g. Barlow 1988; Hiby and Hammond 1989). This parameter is influenced by the definition of dive time. Thus, to allow further comparisons we adopted a definition already used in other tracking studies of blue whales (submergences greater than 60 sec) (Lagerquist *et al.* 2000, J. Calambokidis, Personal communication). Such dive definition does not consider the interval between consecutive blows as dive time, and as such the whole surface interval is considered as time near the surface (or availability). Field data supported the adopted definition. Three of the eight focal-animals exhibited surface swimming regularly during the surface interval, thus being constantly in sight. Observed availability was smaller than reported by Lagerquist and colleagues (2000) (25.4% ±5.4%).

Dive times reported by Lagerquist *et al.* (2000) derived from boat based visual observations were much lower than the average for our study. Their results are comparable only to the animal considered to be traveling in our study. However, average true dive durations reported here were similar to what has been observed in another study conducted in the Pacific by Croll *et al.* (2005). The later reported dive times for two tagged whales of the order of 8.8 min (±0.8) for a mean dive depth of 155 m (±9.8) and of 8.3 min (±1.4) for a mean dive depth of 172 m (±14.7). Dive times reflect animals' main activity (e.g. Dorsey *et al.* 1989) and in the case of foraging animals, they are strongly correlated with the depth of the exploited patch (e.g. Doniol-Valcroze *et al.* 2011). Also, prey aggregation and patch size may have an important effect on dive duration. In the present study we do not have any information on maximum depth of dive, although the observed animals were all restrained to the steep slope at the edge of the St. Lawrence submarine canyon, with depths of up to 218 m. In addition, in the Saint Lawrence the krill tend to be found in a dense scatter layer around 90 m during daylight (Sourisseau *et al.* 2008) and tagged blue whales concentrated their feeding activity during the day light at depths of about 70 - 100 m (Doniol-Valcroze *et al.* 2011). A trend from longer to shorter dives was observed from the day the whales arrived in the area in 2009 to the day they left (Figure 6) what is possibly correlated with decreasing prey availability in the area over the period.

Breathing parameters can also be used to infer activity budgets and verify the effect of human activities on whales' behavior. In the present study, blow rate varied among observed individuals and was a good indicator of their main activity. Also, a short-term effect of boat's presence on the animal's blow rate was identified. Not only blow rate was altered but in one occasion a fast sideways movement of the fluke was executed by an animal in the vicinity of a whale watching boat, which was closer than 100 m of the whale.

These short-term effects might have long-term consequences if feeding success is affected. Blue whales are known to have high energetic demands and their feeding strategy is costly (Goldbogen *et al.* 2011). Due to the species critical conservation status minimising all kind of disturbances is essential to the species recovery.

Several authors point out the need to regulate and enforce whale watching activity in order to make it sustainable and minimize undesirable the effects to the target species (IFAW 1995; Orams 2000; Hoyt 2001; Lien 2001; Corkeron 2004). Short and long-term effects of whale watching activities have been reported for other areas and species (e.g. Glockner-Ferrari and Ferrari 1985; Salden 1988; Baker and Herman 1989; Lusseau 2003; Scheidat *et al.* 2004; Bejder *et al.* 2006; Williams and Ashe 2006; Morete *et al.* 2007; Weilgart 2007; Stamation *et al.* 2010). Short-term impacts included changes in breathing patterns, swimming speed, direction of travel, surface activity, and vocalization rate (Corkeron 1995; Bejder *et al.* 1999; Lesage *et al.* 1999; Lusseau 2003; Constantine *et al.* 2004; Richter *et al.* 2006; Morete *et al.* 2007; Sousa-Lima and Clark 2008; Williams *et al.* 2009) while long-term effects included decreasing reproductive success (Bejder 2005), physiological conditioning, survivability (Lusseau and Bejder 2007) and distribution shifts (Salden 1988; Schick and Urban 2000).

As feeding areas are essential to animals' survival distribution shifts as a consequence of human activities are unusual in addition to being hard to detect as it would require longitudinal studies of the whole ecosystem. Within the St. Lawrence River Estuary the lack of long-term systematic data on prey distribution prevents cause-effect analysis. However, currently, blue whales' occurrence rate in the area is lower than what was reported for the 1970's (Edds and Macfarlane 1987). Even assuming the decrease was due to environmental change or is part of a cyclical pattern of availability of blue whales' prey species, it is essential to improve the quality of the feeding habitats used by the species in Canadian waters as highlighted by the national blue whale recovery strategy. Decrease exposure to marine traffic and to noise pollution are the main goals to achieve the recovery not only of blue whales (Beauchamp *et al.* 2009), but also of the Saint Lawrence beluga whale population (MPO 2011).

5.4.3 Exposure to boats

Quantification of exposure is essential in order to improve management and is generally absent from papers focusing whale watching. To our knowledge, the degree of exposure to whale watching activities that blue whales experience within the SSLMP is not comparable to any other place. Part of this is probably due to a lack of information on the subject. The present study is the first to focus on blue whales and whale watching activities. Overall, quantification of exposure for all cetacean species is lacking. Schaffar *et al.* (2010) provide a first quantification of humpback whales' exposure to non-regulated whale watching around New Caledonia. In addition to the lack of information on exposure, blue whales are generally found in vast areas of open sea. This makes the SSLMP an exceptional place to study the species' exposure to anthropogenic activities and to observe the species in the wild. Downstream from the SSLMP the activity is also offered from the villages of Gaspé, Percé and around the Mingan Archipelago National Park, though the fleet is much smaller and the opportunities for land-based whale watching are much rarer.

Around the world, blue whales' watching is possible from very few locations. In Mirissa, Southern Sri Lanka, whale watching excursions have been offered on a regular basis since 2006 and blue whales are the main target species. The activity runs from November to April, after which the monsoons switch making it difficult for boats to go out in search of whales. In 2010, 12 boats were offering trips (only six boats operate on a regular basis) at most once a day (A. de Vos, Personal communication). In Chile, a concentration of blue whales was discovered in the early 2000s (Hucke-Gaete *et al.* 2004) and whale watching tours are offered in the vicinity of Chiloé Island with a main focus on blue whales. About five boats operate in the area offering trips once a day (weather permitting). Lately, the activity is also being offered from Puñihuil, and Damas Island (Chañaral). In Damas Island, whale watching targets bottlenose dolphins (*Tursiops truncatus*), however, they have had blue and fin whale sightings (C. Olavarria, Personnal communication). In California, blue whales are playing an important role in establishing a more mature, year-round whale watching industry. Both numbers of sightings and locations have increased dramatically over the past few years and some operators are taking advantage of that. Southern California is the birthplace of an organized, boat-based whale watching, which originally focused on the migrating gray whales (*Eschrichtius robustus*). Monterey Bay has the highest density of year round whale watching operators centered in Monterey Harbor, Moss Landing and Santa Cruz. They have a high diversity of cetaceans and rely less on blue whales as they see other species reliably, including humpbacks and killer whales (*Orcinus orca*). Other locations offering whale watching include San Francisco, Morro Bay, Avila Beach, Santa Barbara, Long Beach, Newport Beach, Dana Point and San Diego (B. Alps, Personal communication). In Mexico the activity takes place within the "Parque Nacional Marino Bahia de Loreto" – Loreto - Gulf of California, where the blue whale is the main target (D. Gendron, Personal communication).

The high degree of exposure the whales experience within the Saguenay–Saint-Lawrence Marine Park is also due to the large volume of marine traffic in the area. Not only is the whale watching industry fleet of considerable size, but also the number of private boats and large ships sharing the same restricted area is large (Chion *et al.* 2009). The volume of large ships transiting in the area is comparable to that observed off the Coast of Massachusetts (Hatch *et al.* 2008) with no less than 3135 transits from May to October (Chion *et al.* 2009). In addition, as presented in the Chapter 4, the navigation corridor overlaps areas of high density of blue whales. Commercial whale watching is conducted by a well-developed industry that has been established in the area since early in the 1990s. The creation of the Marine Park was a step to manage its growth, but numbers are well beyond the ideal to improve conservation of the area.

In 2007, the whale watching industry established around the Marine Park was composed of 17 companies. Together they operated 59 boats from which 43 were dedicated exclusively to the observation of marine mammals (Chion *et al.* 2009). Depending on the company and boat type between three and four daily excursions (with a mean duration of 2:30 hours each) are offered by boat. A total of thirty-four zodiacs (including 12, 24 and 48 passengers zodiacs) can be in the waters of the Park at the same time, departing from the three main homeports (Tadoussac, Les Bergeronnes, and Les Escoumins) (Chion *et al.* 2009). To date, there is only one 48-passenger zodiac operating within the SSLMP. Replacement of small zodiacs by bigger ones would help diminish the number of zodiacs on the water and thus whales' exposure (PMSSL 2011) without economic loss for the industry. Improvements to the current whale watching regulations following the adaptive management approach could also decrease exposure.

The marine mammals' observation regulations in the SSLMP lacks clarification concerning the maximum number of boats allowed within an endangered species' observation zone. The regulation states that commercial boats should be further than 200 m if more than four boats are within 400 m of a non-endangered species. But there is no rule in the presence of endangered species. The 400 m distance limits was defined to inhibit the approach of endangered species, but when blue whales are within the Marine Park the whale watching boats will attempt to include it in the excursion. The average number of boats within 1 km of a blue whale observed in the present study was 2.3 (±2.7, max=14) and even if the average was relatively low, the prolonged exposure and the range are of concern. The average obtained from observations made onboard whale watching boats during the same period within the SSLMP was even higher (3.7) and outside it was similar (2.2) (GREMM unpublished data). Based on the species conservation status we strongly recommend that no more than 2 boats be within 1 km (~1/2 nautical mile) of a blue whale. Such a restriction might facilitate monitoring by park rangers and improve captains' compliance with the distance limits (400 m) specified by the whale watching regulation. Besides, this measure shall decrease boat concentration and promote trips diversification.

5.4.4 Boats compliance to actual whale watching regulations

The present work presents the first systematic evaluation of compliance with the regulations for marine activities (SOR/2002-76) adopted by the Marine Park in 2002. Despite the lack of compliance quantified here it has to be acknowledged that the industry has made enormous progress on the subject since the beginning of whale watching activity in the area and in this sense adoption of the regulations was an important step. The regulations were the result of a long consultation process integrating multiple stakeholder perspectives as part of the adaptive and participatory management scheme in place in Canada, a management model that is both research-informed and adaptive (Higham *et al.* 2009). Since 2010, Park managers, the local NGO - Group for Research and Education on Marine Mammals (GREMM) and representatives of the whole industry have been working together ("Alliance Éco-Baleines") with the aim of developing a code of conduct that shall improve awareness and effectiveness of compliance with actual regulations. It has been demonstrated that codes of conduct have the power to be more effective than regulations when developed in conjunction with the industry and if teleologically oriented (as used by Garrod and Fennell 2004) (*i.e.* rules are followed by the consequences of the actions, ex: 'do not cut the path of the whale as this causes the animal to precipitate its dive and affects its physiology').

It is largely known that marine monitoring is expensive; generally the number of park wardens is limited and the lack of automatic devices to prove the occurrence of an infraction make law enforcement difficult. Raising captain's awareness of the importance of compliance to the conservation of the target species is key for establishing sustainable whale watching activities (IFAW 1995; Orams 2000; Hoyt 2001; Corkeron 2004). The success of an awareness campaign relies on an effective behavioral change on the water (e.g. Sorice *et al.* 2007; Wiley *et al.* 2008) and the Alliance that was recently formed within the Marine Park is an initiative that meets the criteria for success.

5.4.5 Implications to conservation and management

Based on the whales tracked in the scope of this work, it would be an important advance if the regulations and/ or the code of conduct specified an angle to approach the animals as a means to minimize animals' disturbance. It is known, for example, that feeding whales may precipitate a dive to avoid boats in their path with direct consequences to their fitness. Such a measure is already contemplated by numerous regulations (Garrod and Fennell 2004; Carlson 2008) and the Department of Fisheries and Oceans encourages private boaters to avoid approaching marine mammals using a ~60 degree angle in front the animal's path (DFO 2009). Such a specification is lacking in the regulation adopted by the park and boats approaching using this angle are quite common in the study area.

The adoption of a federal regulation for whale watching activities in Canada is an old claim (Lien 2001) that has never been achieved at the national level. Improving the current regulation within the park shall contribute to blue whales and other cetacean species conservation but in order to be effective, protection actions should be extended to the whole Economic Exclusive Zone. These long living creatures are completely aware of their environment. Even if all mechanisms regarding whale's memory and navigational abilities are unknown, photo-identification data and large-scale telemetry sensors have shown that animals return to the same feeding areas, year after year and sometimes following the same straight line. Not only do they remember good feeding spots, but they may also remember other important parameters about a particular location. Degree of exposure to human activities and feeding success, among others, might be part of the memory these animals keep in order to maximize their fitness.

Marine Protected Areas have been proposed as an effective measure to enhance marine mammal species conservation (Hooker and Gerber 2004; Hoyt 2005) but proper management is needed to guarantee their effectiveness. The inclusion of speed reduction areas as part of the SSLMP's zoning plan would be of great benefit to all cetacean species using the area. One suggestion would be to limit speed close to the northern shore, for example within one nautical mile from the north shore (the area here denominated as 'northern shore one nautical mile zone'), to a maximum of 10 knots. This would reinforce marine mammals protection while favouring the development of land-based whale watching, which is an important activity in the area. In addition, such a measure would improve marine traffic security as kayaks intensively use this area. It is important to mention that the actual speed limit inside the whole Marine Park is 25 knots. The SSLMP management plan should promote a symbiotic relationship between whales and boats inside the Marine Park. This might be achieved by providing a safe and high quality environment to the cetacean species in order to avoid potential distribution shifts (*e.g.*, whale displacement), which would be negative for this Social-Ecological System (Folke 2006) as a whole.

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Chapter 6

Exposure of humpback whales to whale watching activities in the Saguenay-St. Lawrence Marine Park – Quebec, CA

6.1 Introduction

The humpback whale, *Megaptera novaeangliae*, has been the most intensively studied of the baleen whales (Clapham 2000). They are a cosmopolitan species with a well described migratory behaviour, spending the summer in high latitude feeding grounds and the winter in tropical waters, where calving and breeding take place (Clapham and Mead 1999). The humpback whales that occur at the Saguenay – St. Lawrence Marine Park (SSLMP) belong to the North Atlantic feeding stock and are known to congregate on a common breeding area in the West Indies (Katona and Beard 1990; Stevick *et al.* 1999)(Figure 67).

In the seventies, humpback whales were rarely seen in the Gulf of Saint Lawrence (GSL) (Katona and Whitehead 1981) and some argue that the species was already absent since early in the 1900's as a result of hunting pressure (Mitchell *et al.* 1982). Early records of the species in the marine portion of the St Lawrence River Estuary (SLRE) come from land-based observations conducted from 1972 through 1975 (Mitchell *et al.* 1982). Since that time, the species has been observed almost every year in the area. However, it was just from 1999 on that their presence inside the SSLMP passed from episodic to continuous throughout the feeding season (Michaud *et al.* 2003; Michaud *et al.* 2011). While in the area, the species is a main target for the whale watching industry mainly due to its conspicuous behaviour (Michaud *et al.* 2003). Humpback whales are known for the frequency with which they engage in often spectacular aerial displays (Clapham 2000), making them the main focus for whale watching (WW) activities in many locations worldwide.

Several studies have shown that humpback whales react to the presence of boats in breeding (Bauer 1986; Scheidat *et al.* 2004; Morete *et al.* 2007; Stamation *et al.* 2010) and in feeding areas (e.g. Boye *et al.* 2010). Mother and calf pairs increased mean speed and linearity of displacement, decreased blow intervals and time spent resting in a Brazilian breeding ground (Morete *et al.* 2007). A similar effect in the speed and linearity was observed in Ecuador for different group categories (Scheidat *et al.* 2004). A recent land-based study conducted in a feeding area in West Greenland showed that while in the presence of whale watching vessels the animals significantly increased swimming speed, shortened long dives and diminished the ratio between surfacing and long dives (Boye *et al.* 2010).

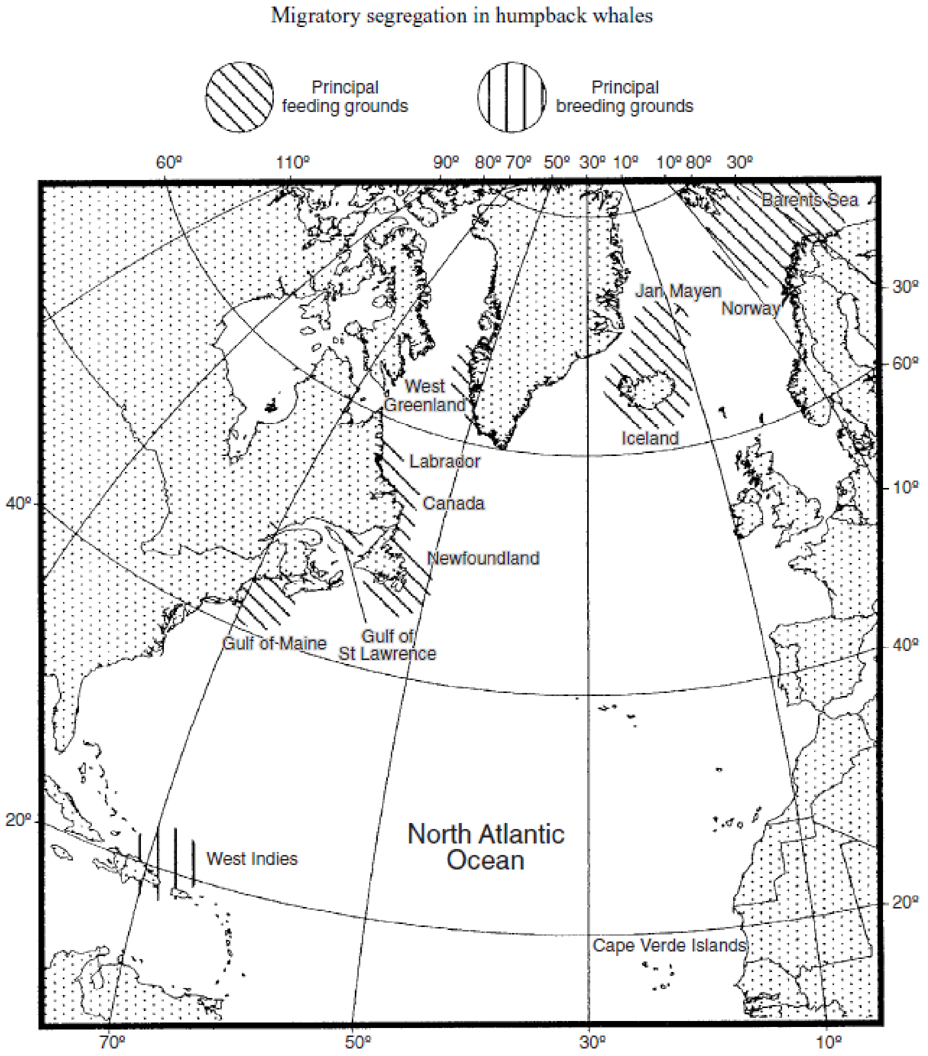

Figure 67. The North Atlantic showing the principal feeding and breeding aggregations for humpback whales (from Stevick *et al.* (2003)).

Although different authors have shown the effect of WW activities on humpback whales, the first study characterising animals' exposure was only recently published. Schaffar *et al*. (2010) presented a characterisation of humpback whales' exposure in New Caledonia, where a small population of humpback whales breed and are the main target of an increasing WW industry. The activity is not regulated to date and animals' exposure was considered to "exceed the limits commonly recommended by management measures worldwide" (Schaffar *et al.* 2010). During two years of land-based observations, 54% of the observed groups were accompanied by boats.

Worldwide, whale watching activities are regulated through local guidelines or federal laws. Carlson (2001; 2008) presented the most up dated version of the available codes of conduct (here used as a general term to indicate a set of rules - voluntary or imposed - designated to regulate whale watching independently of its jurisdiction). In general, they all regulate distance limits, and prudence zones around the target animal within which speed and maximum number of boats allowed are limited. Garrod and Fennell (2004) provided an in depth review of the 58 codes of conduct previously compiled by Carlson (2001). In their analysis (which includes guidelines to cetaceans' in general as long as specific to whales or dolphins) they found that the most common approach distance limit was in the range of 50 to 99 m (41.4 % of all codes), followed by 100 m (25%). Of 31 codes that mentioned a maximum number of boats around a target species, 15 codes suggested no more than one boat at a time, nine codes specified two, six codes recommended three boats and one code suggested six boats. The most common allowable observation time was 30 minutes, while the mean dwelling time for the 27 codes of conduct providing information of this sort was 41.7 minutes (sd=76.2) (Garrod and Fennell 2004).

Although some codes of conduct provide information on dwelling time, the rules are usually general. Notwithstanding, as the study on the effects of whale watching on specific populations increases, more specific regulations have been recommended. Recently, a study focusing on bottlenose dolphins (*Tursiops aduncus*) in Australia recommended a restriction in the number of operating boats after one –o'clock p.m. within the limits of a marine park (Steckenreuter *et al.* 2012). The adoption of more specific regulations is often consequence of comprehensive studies, and in general, is applied to small populations with restricted distributions, what is usually the case mainly for dolphins (e.g. Bejder *et al.* 2006).

Measures that limit animals' daily exposure are generally lacking (Garrod and Fennell 2004), a matter that may not represent an issue for many populations that are focus of WW activities. A rapid overview of some humpback whale populations, for example, will result in populations estimated at over a thousand animals, distributed over large portions of the continental platform and over hundreds of kilometres along the coast line (e.g. Andriolo *et al.* 2006; Andriolo *et al.* 2010; Stamation *et al.* 2010). For most humpback whale populations, the probability of the same whale being watched twice in the same day, by the same boat or by more than one whale watching boat tends to zero. In such cases, the general regulations found in the current codes of conduct may be enough to ensure animals' protection. However, as presented in the previous chapters, this is not the case in the SLRE. The intrinsic characteristics of the region limit the number of animals that use the area. However, these animals spent a large period of the year in the same place. This is a period of time during which the most essential activity of their life cycle takes place: feeding. In addition, they usually return to the same feeding area for their whole life time, which spans several decades.

Whale watching is an amazing experience and its value to whales' conservation worldwide is undeniable. In the other hand, the whales guarantee an important economic activity. But how to find the balance? Do current regulations ensure protection to the animals that sustain local activities? How to know how much is too much? How can a regulation limits the "too much"? In other words, how ensure a trade off between the benefits of the activity and its impacts? Here, land-based tracking of humpback whales collected over three consecutive field seasons (2008-2010) within the Saguenay St. Lawrence Marine Park were used to characterise their daily exposure to boats. A discussion of possible measures to enhance the animal's protection is provided and may guide stakeholders to find a balance.

6.2 Material and Methods

6.3.1 Study area and period of research

The study area was located within the marine portion of the Saguenay St. Lawrence Marine Park (SSLMP) (Figure 68). Observations were conducted from four land-based stations: 1) Bergeronnes (16.102 m above sea level (*asl*)), 2) Camping *Mer et Monde* (18.343 m *asl*), 3) Escoumins (13.431 m *asl*) and 4) Pointe Noire (38.305 m *asl*). The land-stations were equipped with a total station, a topographic device that allows positioning whales and boats under observation. Heights of the land-based stations were measured with a Differential Global Positioning System (DGPS), thus are considered to be accurate. Observational efforts were limited to a three nautical mile (~ 5.5 km) radius to minimize positioning errors. A 10 cm error in the instrument's height *asl* at an elevation of approximately 15 m provides an accuracy of [-38, +39] m for targets at 5 km, of [-17, +17] m for targets at 2.500 km and of [-3, +4] m at 0.5 km (Würsig *et al.* 1991). It was assumed that the humpback whale positions data lead to a maximum error of 40 m (see Annexe 4 for details). Observations were limited to good weather conditions (visibility over 8 km and wind below 16 knots). The study covered part of the core area of whale watching activity and the peak of the touristic season (Michaud *et al.* 2011). The research was conducted from late July to early September from 2008 to 2010. The field-work was planned to cover all the day light period, from 7 am to 8 pm (weather permitting).

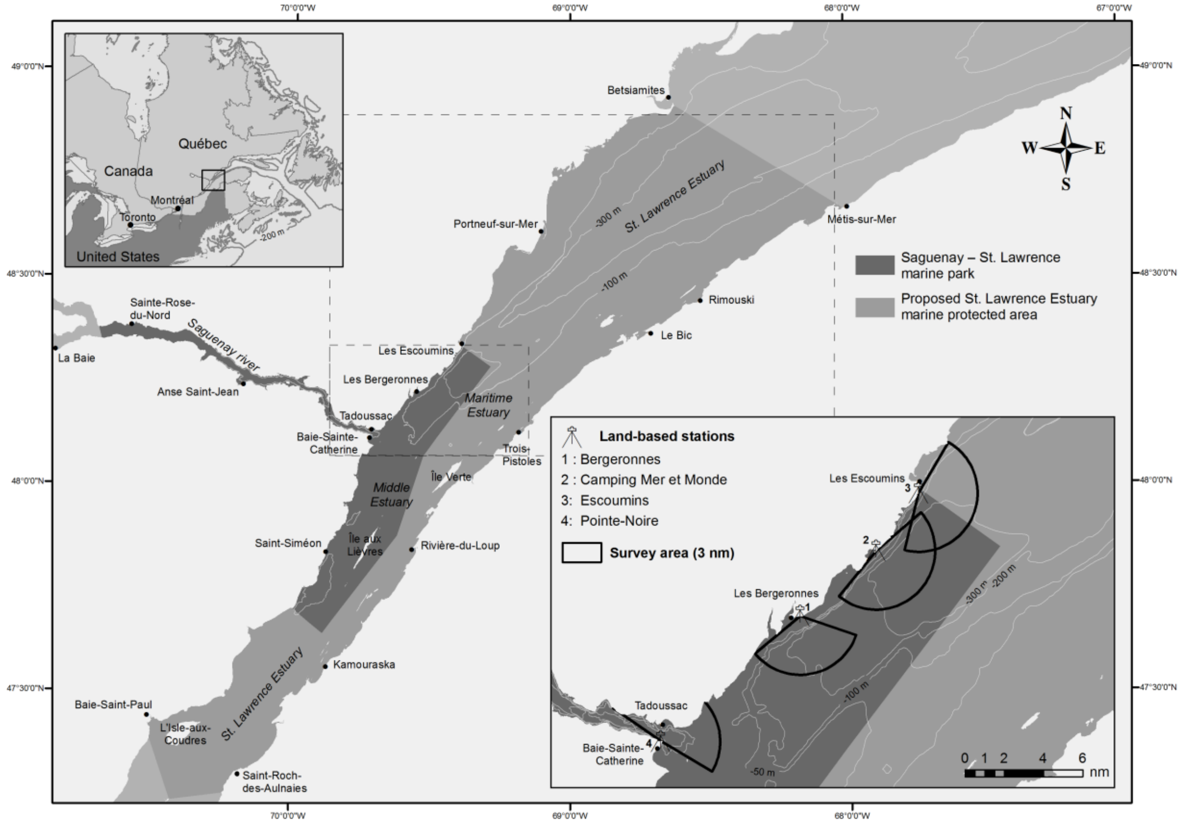

Figure 68. Boundaries of the Saguenay – St. Lawrence Marine Park, the proposed St. Lawrence Estuary MPA and the land-based stations from which focal-animal observations of humpback whales were conducted.

6.3.2 Data collection protocol

Humpback whales were tracked from the coast using a total station (Leica TC805L and TCR1103). Individual whale movement data were collected following a focal-follow protocol and continuous sampling method, both of which are best applied to follow single or paired animals, which were the main focus of this study (Altmann 1974; Mann 1999).

Observations were systematically carried out by two observers, one using the total station and another assisting with a pair of binoculars (7x50 Bushnell). While tracking the focal-animal, observers attempted to position all blows while recording all observed behaviours at a second precision. Adopted behavioural events are listed and defined in Table 19.

Table 19. Adopted ethogram for the land-based observations of humpback whales.

Behaviour	**Adopted definition**
Arching	Pronounced arching of the peduncle typically observed before a true dive
Blow	The animal emerges from a submergence period and opens its blowhole to exhale (usually forming a visible cloud of warm moist air) and inhale the air.
Breach	The whale body is completely or almost completely projected out of the water.
Caudal curl	The tightly arched back of the whale is held or raised in an arch above the water, with little rolling movement, while the whale continues to move forward (Mitchell *et al*. 1982).
Fluke-up dive	The fluke is completely (>45º) or partially rose above the water typically preceding a true dive.
No Blow	The animal emerges from a submergence and the blow spray is not observed. Only attributed to animals tracked within 2 km.
Surface swimming	Animal moves forward very slowly (sometimes only following the surface current) without completely submerging its body in between consecutive blows.
Surface feeding	Animal surfaces with the jaw at least partially opened.
Tail slap	The animal lifts its tail out of the water and brings it down onto the water surface very fast. Most of the times the movement is made with the ventral side of the tail reaching the water but the dorsal side can also be used and when it happens, the animal usually hits the surface with the dorsal side and them with the ventral side consecutively.

All boats within the binocular observer’s field of view were positioned at least twice using the total station and boats within a 1 km radius of the focal-animal were positioned before and after the focal-animal surface interval and whenever they moved actively. Boats were classified according to their types and sizes as whale watching zodiac, big whale watching boat, kayak, private boat and research boat. Each time boats were positioned, their behaviour was classified as approaching or leaving the focal-animal, accompanied by a visual classification of their movement pattern: moving slowly (boat moving while producing some white caps), and moving fast (boat moving at higher speeds and producing a lot of white caps and spray in the water) and still (boat moving very slowly with no white caps around it characteristic of a boat in observation of a cetacean).

Focal-animals were chosen after systematically scanning the observation area. Choice was based on distance from shore and group composition, preference being given to single individuals. Individual identification during tracking was regularly verified using distinctive characteristics of the focal-animal (*i.e.,* scars, natural markings, shape of dorsal fin). Observations were terminated if the identity of the focal-animal was not ascertained, if animals moved beyond the study area limit or weather conditions became unfavourable. Only *ad libitum* information on other marine mammals was collected.

A team of three persons was present at each site: the two observers mentioned above (total station operator and binocular observer) and a note taker. The total station operator was responsible for taking all the positions by recording a vertical and a horizontal angle that corresponded to the target position and to dictate all observed behaviors to the note recorder. Coordinates were registered into the total station memory and were downloaded every day (see field work protocol in Annexe 3). In order to ensure maximum consistency, three experienced observers shared the role of total station operator, and within short (shorter than one hour) focal-follows (FF) the total station operator was always the same. At the same time, the note recorder registered time (at the second precision) of all observed behaviours and the position code (when available). The binocular observer was equipped with a 7x50 Bushnell and his/her function was to assure that the total station operator did not miss any behaviours of the focal-animal. This was necessary due to the total station magnification (30 times), as animals moving too fast or with long dives might return to the surface outside the total station's field of view. The binocular observer also would warn the team of the arrival of boats and other marine mammals in the observation area.

Collected data were examined at the end of each observation day in order to determine data quality. For the purpose of this analysis all focal-follows longer than 25 minutes and without gaps in the observation sequence were kept.

Cyclopes® (Kniest 2004) was used to transform vertical and horizontal angles measured by the total station into latitude and longitude by taking local tide height variation (transcribed from official Canadian charts) into account.

6.3.3 Marine Activity Regulations

The Marine Activity Regulations (SOR/2002-76) in application within the SSLMP, determines minimum approach distances depending on the boat type (commercial or private) and on species conservation status. The closest distance of approach for commercial boats observing a non-endangered species (as humpback whales) is 100 m, and for private (recreational boats) boats is 200 m (Figure 69). If more than four boats are within 400 m of a commercial boat, the pilot of the latter shall not permit the vessel to approach within a distance of less than 200 m of the target species. Vessels must respect a 400 m distance for endangered species (blue and beluga whales). In addition, based on the definition of *observation zones,* speed reduction, maximum number of boats and duration of residence within the zone are regulated.

An observation zone is defined as "a moving circular zone that exists around a vessel while it is in observation mode and has a radius of one nautical mile from the vessel to the perimeter of the zone" and an observation area is defined as "two or more overlapping or contiguous observation zones" (SOR/2002-76). Speed is limited to 10 knots within an observation zone of another vessel or within an observation area. Commercial boats residence time is limited to two periods of 30 minutes each during each excursion. In addition, they shall not approach the same animal more than once during the same excursion and shall not return to the same observation area or observation zone until one hour has elapsed after leaving that observation area or zone (SOR/2002-76).

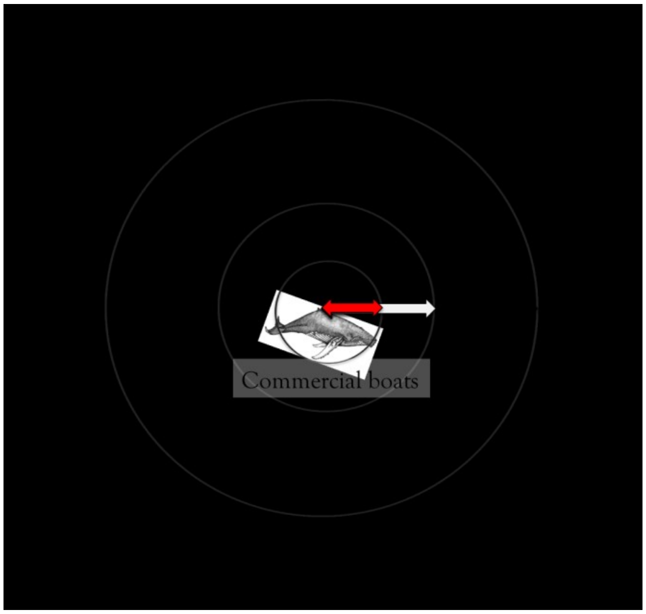

Figure 69. Area surveyed during land-based data collection (1 km), distances adopted to characterize exposure, and distances to be respected by the whale watching boats depending on boat type (commercial versus recreational boats).

The current regulation is under review, and among the proposed modifications and new rules some are of interest. The new regulation reduces the 10 knots speed restriction to ½ nm from other observing boats. In addition, the number of boats within the observation zone is limited to 10. In the previous regulation there was no mention of the number of boats allowed within an observation zone. Another proposed rule is to forbid approaches within 200 m of animals at rest or accompanied by a calf. The proposed modifications to the SOR/2002/76 were presented and discussed by Chion *et al*. (2012).

6.3.4 Data treatment to characterize exposure to boats

Exposure was defined as the time interval during which the target animal was accompanied by at least one boat within a 1 km radius. It was expressed as a percentage of the total observation time and was calculated for each FF (individual exposure) and for the whole observation period (total exposure). A period without boats was defined as any interval equal or greater than 10 min during which no boats were recorded within 1 km of the focal animal. In order to verify if the exposure varied throughout the day the observation period was divided into three periods: morning - from 7 am to noon; afternoon – from noon to 4 pm, and evening – all observations conducted after 4 pm.

In addition, the total number of boats in observation at the same time, by boat category and by land-based station was compiled. For this analysis, for each whale position, the distance to all boats within a 1 km radius was calculated. A code was written in R 2.10.1 (R Development Core Team 2009) to perform this operation. The consecutive positions of the same boat (based on the boat identifier) were interpolated in order to have the distance to the target whale at each blow interval. This operation was necessary to ensure that all boats around the target animal were counted at each blow. As humpback whales do not have as marked behaviours as blue whales (presented in the previous chapter) it was not possible to position all boats before and after the focal animal surface interval.

Exposure was measured by boat type and distance category. Results were organized into seven distance categories: <1000 m (or total exposure, a distance equivalent to the proposed observation zone in the new regulation), 0 – 400 m, 100 – 400 m; 0 – 100 m (non compliant boats); 100 – 200 m, 200 – 400 m, 400 – 1000 m. The value assigned to any distance category represented the maximum number of boats (by boat type) around the target animal at each whale position. Average, standard deviation and maximum exposure were presented. All whale - boat interactions occurred on an opportunistic basis, meaning that observers were not in communication with boats crossing the observation area and did not interfere with boat behaviour.

6.3 Results

From 2008 to 2010, a total of 81.2 hours of humpback whale behaviour data were collected, however, almost half of the tracking time was excluded from the analysis (Table 20) based on the adopted data quality protocol. A total of 33 focal-follows (FF) were retained for analysis, summing 50.4 hours of tracking, and 62.1% of the total tracking time.

Table 20. Total land-based tracking effective effort for each year and percentage kept to characterize humpback whales' exposure to whale watching activities at the peak of the touristic season within the Saguenay St. Lawrence Marine Park.

Year	Σ tracking (hour)	Σ analysis (hour)	% of total	n tracks
2008	14.5	6	41.4	5
2009	22.4	9.3	41.5	4
2010	44.4	35.1	79.1	24
All years	81.2	50.4	62.1	33

The FFs retained for the present analysis were collected from the 7th to the 27th August in 2008, from the 5th to the 24th August in 2009 and from the 25th July to the 21st August 2010. Most of the data were collected from Bergeronnes and Camping *Mer et Monde*, where effort was concentrated after the pilot study conducted in 2008 (Figure 70). Only one FF was conducted at Escoumins, of a whale named *Perseides* that was observed at Camping *Mer et Monde* in the same day moving downstream. Also just one FF was conducted from *Pointe Noire*, even though it is a very unusual location for humpback whales., the whale named *Aramis* was observed in the area for 3 consecutive days.

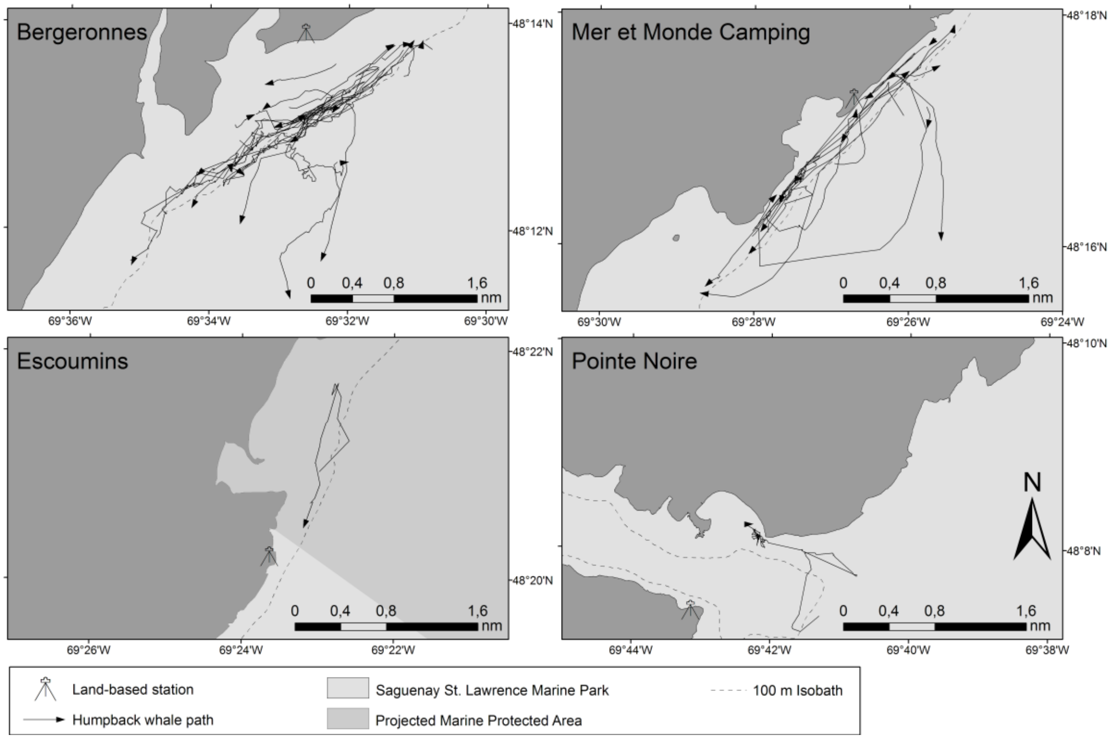

Figure 70. Humpback whales' tracks recorded from four land-based stations at the peak of the touristic season from 2008 to 2010.

Humpback whales were tracked for an average of 1.4 h (±0.7, range= 0.4 - 3.4 h). A total of 19.6 hours of tracking were conducted in the morning (n=14), 17.4 hours in the afternoon (n=7) and 13.3 hours in the evening (n=7). Two FFs lasted from the morning to the afternoon and two from the afternoon to the evening (Table 21). They were split to compute exposure for each day period. It has been possible to identify the individual based on its natural marks in 22 of 33 FFs. Four individuals were thus recognised: *Aramis* (n=1), *Blanche-Neige* (n=2), *Petit Prince* (n=13) and *Perseides* (n=6).

Among the boat categories observed in the study area, four were recorded during the FFs: commercial zodiacs (from now on referred as zodiacs), kayaks and private boats (Table 22). Private boats included sailing and motorised boats of different kinds. A research boat was recorded during one FF, but this boat type was not kept for further analysis. Only one tracking session was conducted without any boat approach, a FF conducted from Bergeronnes (CC100811M) in the evening, which lasted 2.12 hours (Table 22). In only five of the 33 FFs, the whale was not approached by zodiacs. Kayaks were present in all FF made from *Mer et Monde* Camping. Private boats were observed in nine of the 21 FF conducted from Bergeronnes. Due to the higher frequency of zodiacs, the results of exposure will be presented for all types of boats combined (zodiacs + kayaks + private boats) and for zodiacs only.

Table 21. Duration, period of the day (M: morning; A: afternoon; E: evening), exposure to all boat types and to commercial zodiacs, and identity (AR: Aramis, BN: Blanche Neige, PP: Petit Prince, PS: Perseides, UK: unknown) of each individual focal follow retained to characterise humpback whale' exposure to whale watching activities within the Saguenay St. Lawrence Marine Park (*split to compute exposure by period).

				Exposure (%)		
Year	**Track ID (Site yymmdd ID)**	**Period**	**Duration**	**All boats**	**Zodiacs**	**Animal ID**
2008	CC 080807 U	E	0.7	100.0	100	UK
	MM 080820 A	M	0.5	100.0	0	UK
	CC 080826 A1*	M	0.4	0	0	UK
		A	1.4	76.1	76.1	
	CC 080826 A2	A	1.4	100.0	100	UK
	CC 080827 A	M	1.6	75.9	57.1	UK
2009	PN 090805 A	M	3.4	82.7	70	AR
	ES 090813 A	A	2.4	85.4	79.4	PS
	MM 090815 A*	A	2	100	100	PS
		E	0.8	100.0	100	
	CC 090824 J	M	0.7	100.0	100	UK
2010	CC 100725 B	M	0.4	100.0	100	UK

CC 100727 A	M	1.1	61.5	48.8	UK
CC 100727 M	M	1.2	100.0	100	UK
CC 100727 G	E	1.4	67.3	41.3	UK
CC 100730 C	M	0.6	100.0	100	UK
MM 100730 J	E	2.9	93.2	47.3	PP
CC 100801 A	M	3.0	95.9	95.9	PP
CC 100801 T	E	1.4	83.5	18.6	PP
MM 100805 A	M	1.6	100.0	39.5	PP
MM 100805 B	A	1.8	100.0	100	PP
MM 100805 P	A	1.8	15.2	0	PS
MM 100808 C	A	0.7	100.0	100	PP
CC 100808 A*	A	0.96	100	100	PP
	E	1.44	45	27.4	
MM 100810 D	M	1.1	100.0	71.1	PP
CC 100811 M	E	2.1	0.0	0	BN
CC 100811 B	M	0.9	100.0	100	PS
CC 100813 XX	E	1.5	87.2	27	PP
CC 100814 T*	M	0.7	14.2	0	PS
	A	0.7	36.2	36.2	
CC 100818 F	M	1.0	100.0	86.6	PP
CC 100818 J	E	1.1	63.7	0	BN
CC 100819 G	A	2.1	100.0	100	PS
MM 100820 D	A	0.96	100.0	45.3	PP
MM 100821 B	M	1.4	86.0	0	PP
CC 100821 B2	A	1.2	100.0	72.6	PP

Table 22. Number of focal-follows conducted from each land-based station at the peak of the touristic season within the Saguenay-St. Lawrence Marine Park in the presence and absence of each boat type.

Site	**Total tracks**	**With boats**	**Zodiacs**	**Kayaks**	**Private**	**Without boats**
Bergeronnes	21	20	19	6	9	1
Mer et Monde	10	10	7	10	3	0
Escoumins	1	1	1	1	1	0
Pointe Noire	1	1	1	0	0	0
Total	33	32	28	17	13	1

Humpback whales' were exposed to boats (all types combined) within a 1 km radius 78.5% of the observation time and to commercial zodiacs 61.1% of the observation time. There was no statistically significant (*p-level* of 0.05) difference of exposure among the three periods of the day (Tukey's Honest Significant Difference method), neither for all boat types combined nor for zodiacs only. However, in the evening the percentage of exposure to zodiacs was lower than in the morning and afternoon (Table 23, Figure 73).

Table 23. Humpback whales' exposure to boats within a 1 km radius for each period of the day at the peak of the touristic season within the Saguenay-St. Lawrence Marine Park.

		% Exposure	
Period	Σ Tracking (hour)	All boats	Zodiacs
Morning	19.6	78.7	65.2
Afternoon	17.4	67.4	77.5
Evening	13.3	86.1	33.9

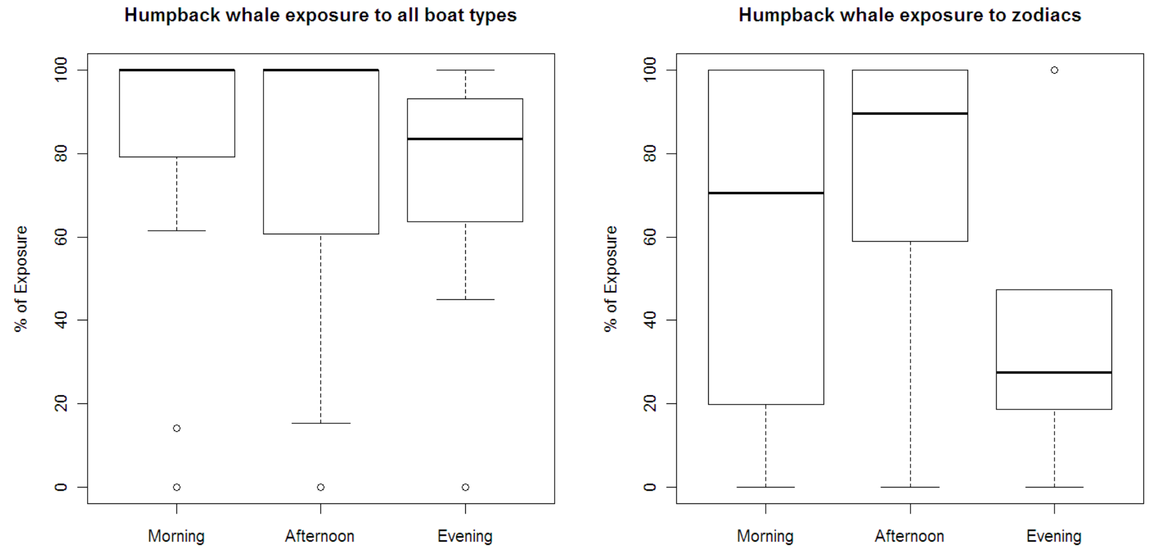

Figure 71. Humpback whales' exposure (*i.e.* percent of time a whale has at least one boat within a 1 km radius) for each period of the day at the peak of the touristic season within the Saguenay-St. Lawrence Marine Park (outliers are shown).

Short and long FF presented high percentages of individual exposure (Table 21). Average total exposure to boats (all types combined) was 78.2% (±33.2) and average total exposure to zodiacs was 60.5% (±39) (Table 21). A total of twenty-seven tracks were of whales in the presence of boats for more than 75% of the tracking duration, and 18 were accompanied by boats during the whole tracking session. A total of ten FF lasted less than an hour, and nine of them were in the presence of boats 100% of the time. Sixteen FF lasted between 1 and 2 hours, and the mean exposure was of 82.3%. Seven FF lasted more than 2 hours and the mean exposure was of 79.6%. In 2010, the whale named *Petit prince* was tracked for 19.5 hours (13 different tracks) and was accompanied by boats 95.2% of the time.

Regarding the exposure to zodiacs only, 16 FF were of whales in the presence of zodiacs for more than 75% of the track duration, and 12 FF were accompanied by zodiacs

100% of the tracking session. From the 10 FF, which lasted less than an hour, seven were in the presence of zodiacs 100% of the time. For the sixteen FF that lasted between 1 and 2 hours, the mean exposure to zodiacs was 52.4% and for the seven FF that lasted more than 2 hours the mean exposure was 70.4%. Individual exposure to zodiacs throughout the day is plotted in Figure 73.

The periods without zodiacs for the animals tracked from Bergeronnes do not match the short intervals (30 min) between excursions for commercial zodiacs that depart at the vicinity of the land-based station (port of Les Bergeronnes) (Figure 72). This pattern might be partially explained by the continuous presence of zodiacs from the other main ports in the water (Figure 72).

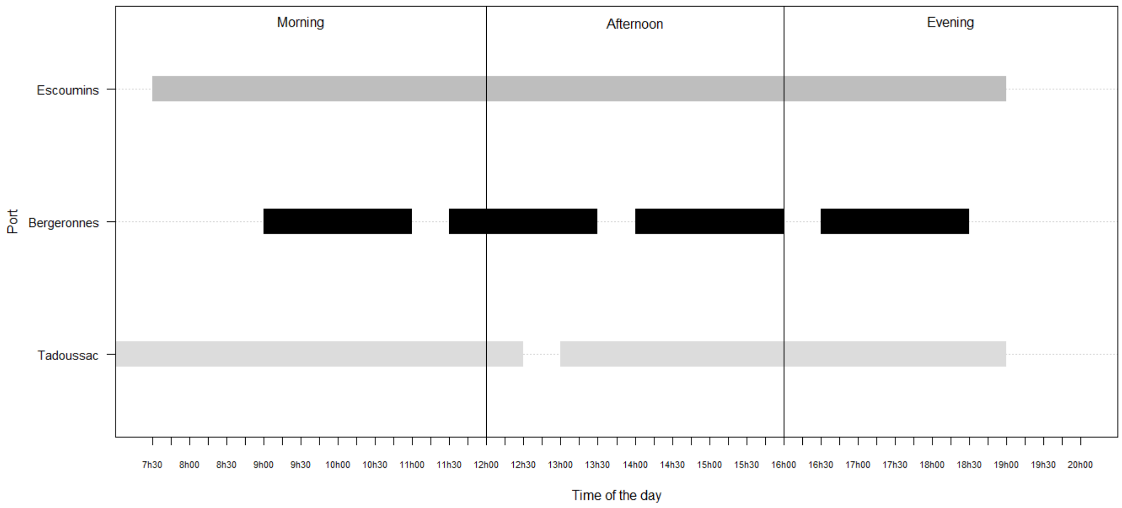

Figure 72. Periods throughout the day during which commercial zodiacs' from each of the three main ports within the Saguenay-St. Lawrence Marine Park can be engaged in whale watching activity according to the published schedule of each company operating in the area (assuming that at the peak of the season all offered trips take place).

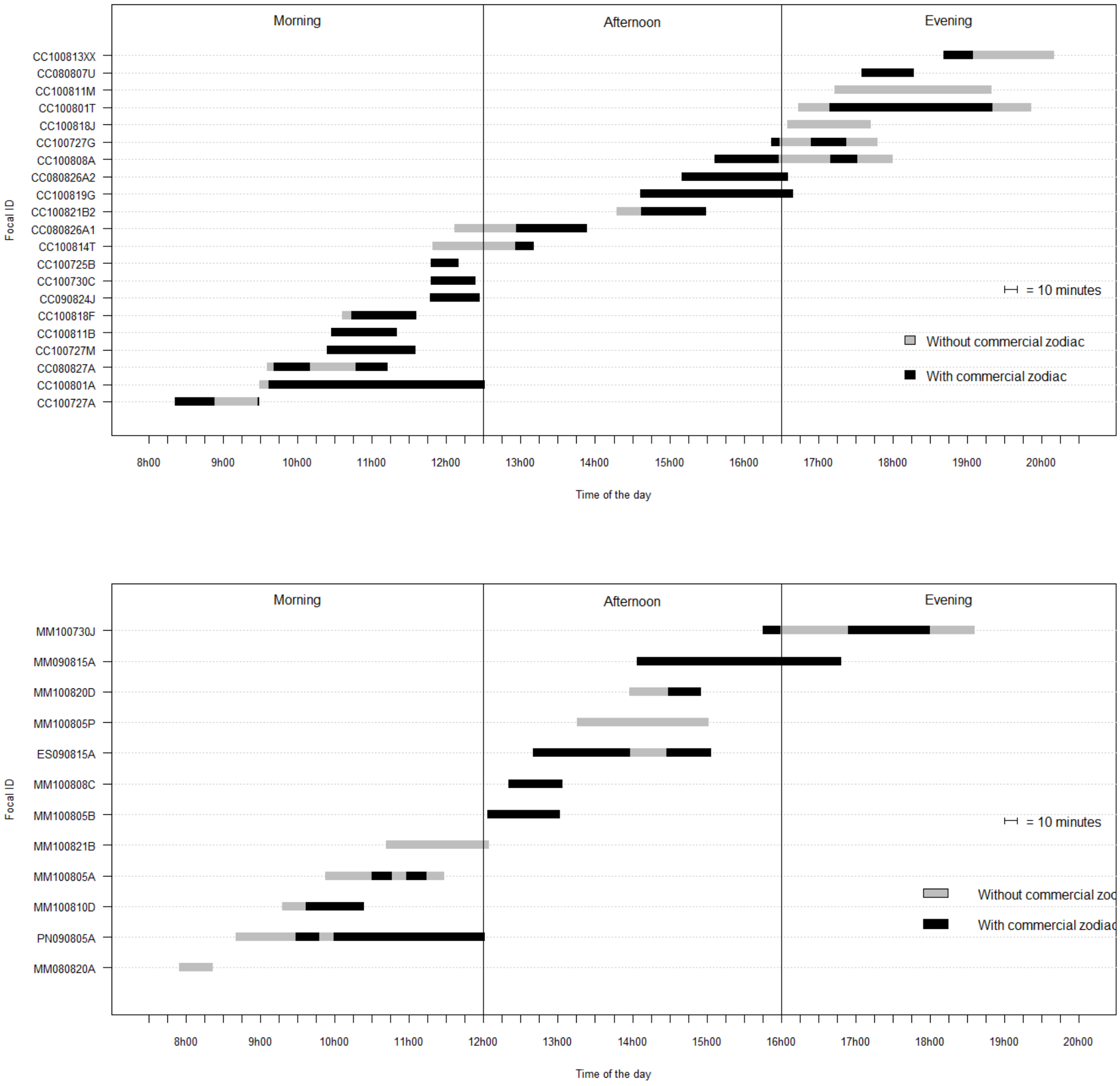

Figure 73. Exposure of each individual focal-follow to commercial zodiacs, throughout the day at the peak of the touristic season at Saguenay-St. Lawrence Marine Park.

The maximum number of zodiacs recorded within a 1 km radius of a target whale was 22, which were recorded at *Mer et Monde* (MM). The average by site and combined (for all sites together) was of the same order, but at MM a slightly higher average and standard deviation were recorded (2±2.7) (Table 24, Figure 74). At Bergeronnes, the maximum number of zodiacs within 0-400 m was nine, while at MM and for all sites combined it was 22 (Table 24, Figure 75). For the distance interval 0-100 m, *i.e.* the distance that the boats should avoid, a maximum of five zodiacs at the same time was recorded at Bergeronnes and nine at MM and all sites combined. For the distance interval 100-200 m, *i.e.* the distance to be respected if less than four other boats are in the vicinity, a maximum of four zodiacs was recorded at Bergeronnes and eleven at MM and all sites combined. The average number of zodiacs between 200-400 m of the target animal was slightly higher than the average between 100-200 m at Bergeronnes and for all sites combined, while it was slightly smaller at MM. Thus, at MM not only they were in higher number, but also more concentrated around the animal. In addition, it was also at MM a higher number of kayaks (average and maximum) were recorded (Figure 74, Figure 75).

The average number of kayaks within a 1 km radius of a humpback whale in all sites combined was 2.1(±5.6), while in Bergeronnes the average was lower (0.6±1.7) and in MM much higher (6.7±9.6) (Table 24, Figure 74). A maximum of 46 kayaks was recorded within a 1 km radius at MM and for all sites combined, while a maximum of eight was recorded at Bergeronnes (Table 24, Figure 75). Although the average number of private boats within a 1 km radius of humpback whales tracked in the present study was very low (0.2±0.4, max=3), they were also recorded within 0-100 m of the target animal.

Table 24. Mean, standard deviation (sd) and maximum (max) number of boats by distance category recorded (for the main land-based stations and for all land-based stations combined) while tracking humpback whales at the peak of the touristic season within the Saguenay St. Lawrence Marine Park (* maximum of boats recorded at the same time within 100 m).

Station	**Distance category**	**Zodiac**			**Kayak**			**Private**		
		Mean	**SD**	**Max**	**Mean**	**SD**	**Max**	**Mean**	**SD**	**Max**
Bergeronnes	0 – 1000 m	**1.9**	**2.2**	**14**	0.6	1.7	8	0.1	0.4	3
	0 – 400 m	**1.3**	**1.6**	**9**	0.3	1.2	8	0.1	0.3	2
	100 – 400 m	1.0	1.4	8	0.3	1.1	8	0.1	0.3	2
	0 – 100 m	**0.3**	**0.8**	**5***	0.1	0.5	6	0.0	0.2	**1***
	100 – 200 m	0.4	0.7	**4**	0.2	0.9	8	0.0	0.2	2
	200 – 400 m	0.6	1.1	7	0.1	0.6	8	0.0	0.2	1
	400 – 1000 m	0.5	1.2	7	0.3	1.1	8	0.1	0.2	2
Mer et Monde	0 – 1000 m	**2.0**	**2.7**	**22**	**6.7**	**9.6**	**46**	0.1	0.4	2
	0 – 400 m	**1.4**	**2.6**	**22**	5.4	8.7	33	0.1	0.3	2
	100 – 400 m	1.0	2.0	**20**	3.5	6.2	31	0.0	0.3	2
	0 – 100 m	**0.5**	**1.2**	**9***	1.9	4.1	25	0.0	0.1	**2***
	100 – 200 m	0.6	1.3	**11**	1.7	3.9	21	0.0	0.3	2
	200 – 400 m	0.4	1.0	11	1.7	3.7	27	0.0	0.1	1
	400 – 1000 m	0.6	1.4	7	1.3	3.1	26	0.0	0.2	2
All	0 – 1000 m	**1.9**	**2.3**	**22**	**2.1**	**5.6**	**46**	0.2	0.4	3
	0 – 400 m	**1.4**	**1.9**	**22**	1.6	4.9	33	0.1	0.4	3
	100 – 400 m	1.0	1.6	**20**	1.1	3.5	31	0.1	0.3	3
	0 – 100 m	**0.4**	**0.9**	**9***	0.5	2.2	25	0.0	0.2	**2***
	100 - 200 m	0.4	0.9	**11**	0.6	2.2	21	0.1	0.3	2
	200 - 400 m	0.5	1.1	11	0.5	2.0	27	0.0	0.2	2
	400 - 1000 m	0.5	1.2	7	0.5	1.8	26	0.0	0.2	2

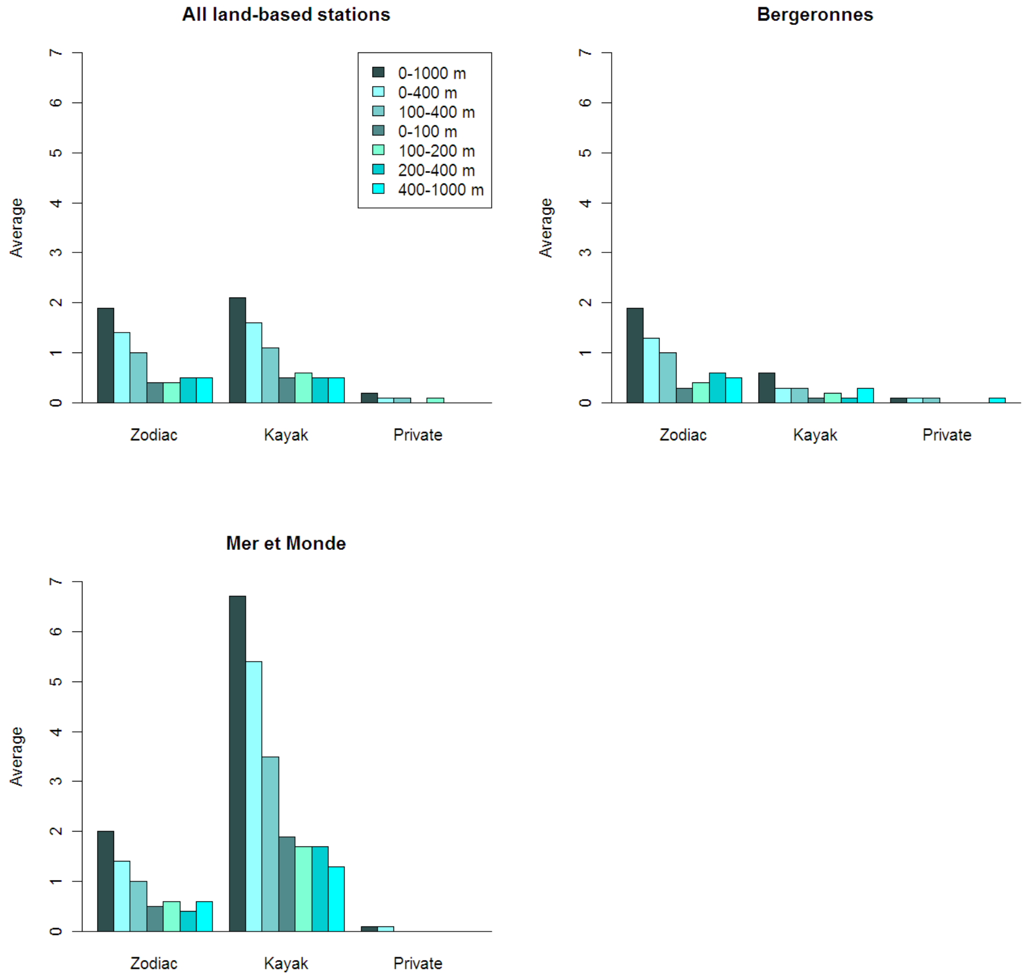

Figure 74. Average number of boats by distance category recorded (for all land-based stations combined and the main land-based stations) while tracking humpback whales at the peak of the touristic season within the Saguenay St. Lawrence Marine Park.

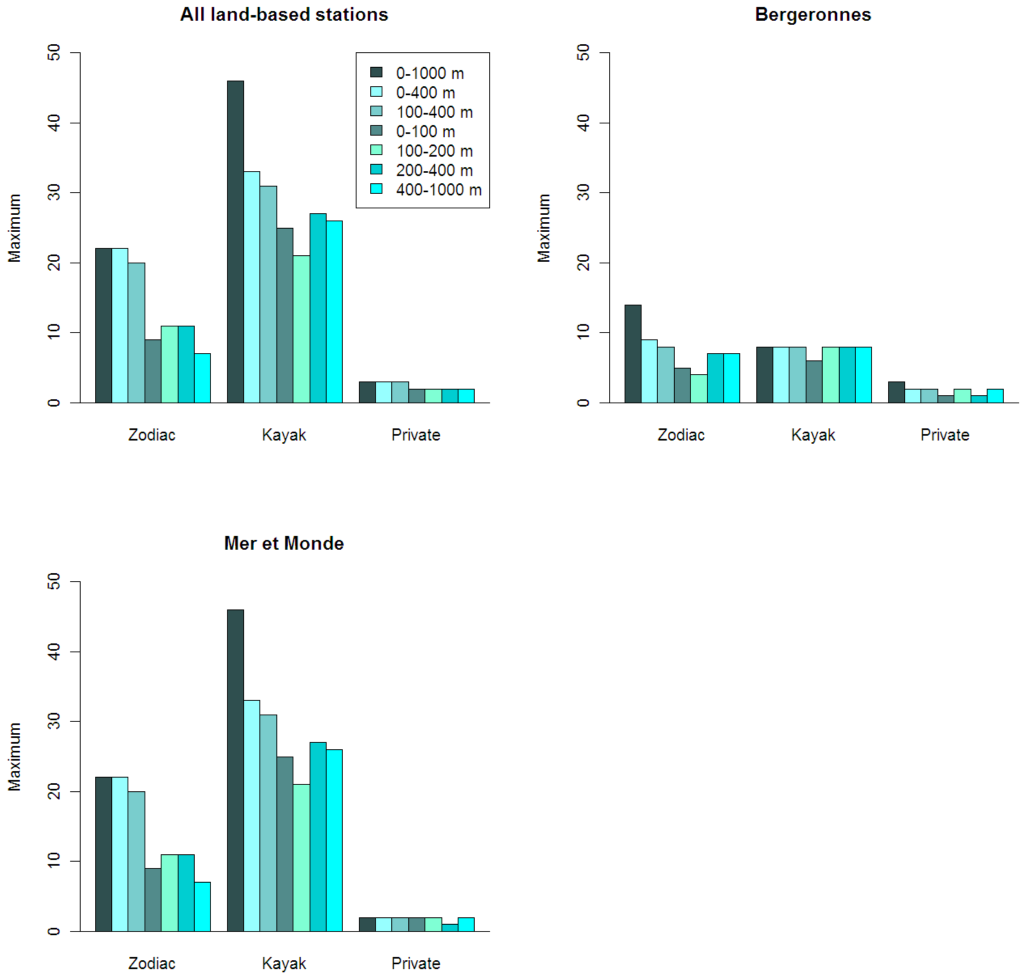

Figure 75. Maximum number of boats by distance category recorded (for all land-based stations combined and the main land-based stations) while tracking humpback whales at the peak of the touristic season within the Saguenay St. Lawrence Marine Park.

Among the identified humpback whales here tracked, the whale identified as Perseides was tracked in 2009 and 2010 (Table 25) in different health conditions (Figure 76). Due to the poor health conditions of the animal since its arrival in the feeding ground in 2010, the *Groupe de Recherche et Éducation sur les Mammifères Marins* (GREMM) asked the commercial boats to avoid approaching it from the 30th of July on. The whale was tracked on four occasions afterwards. On the first occasion, the track conducted from *Mer et Monde* - August 5th 2010, the research boat of the GREMM was observing the animal from a safe distance and no boats approached the animal. In the absence of the GREMM, in the consecutive days, the whale was exposed to boats 100% of the time during two FFs (Table 25).

Table 25. Summary of the focal-follows of the humpback whale identified as Perseides conducted within the Saguenay St. Lawrence Marine Park. (* focal-follows conducted after the 30th of July 2010 when a notification to avoid approaching the whale was emitted).

Year	**Track ID (Site yymmdd ID)**	**Σ Tracking (hour)**	**Exposure zodiacs (%)**
2009	ES 090813 A	2.4	79.4
	MM 090815 A	2.8	100.0
2010	MM 100805 P*	1.8	0
	CC 100811 B*	0.9	100.0
	CC 100814 T*	1.4	36.2
	CC 100819 G*	2.1	100.0

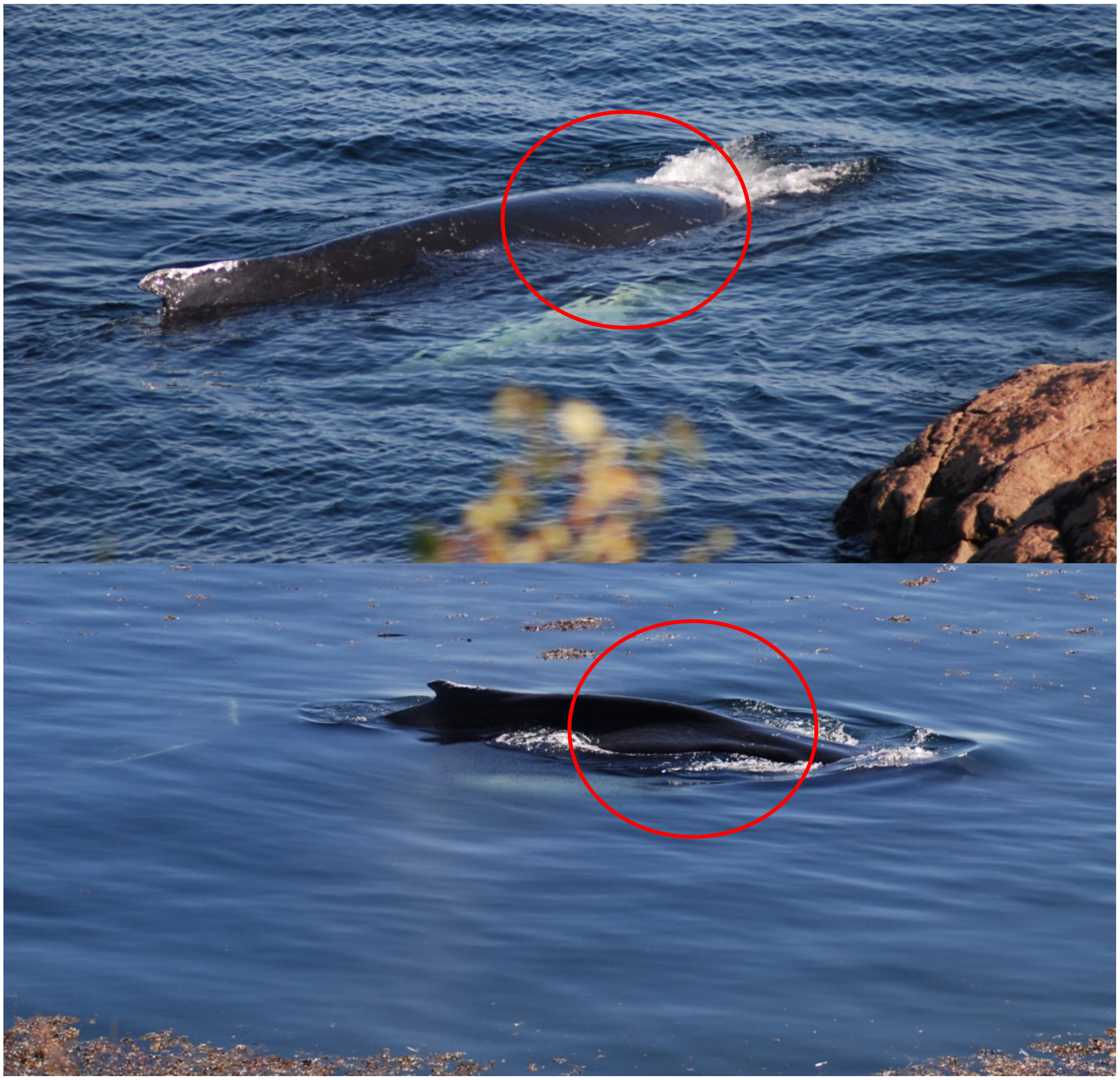

Figure 76. The humpback whale identified as *Perseides* observed from *Mer et Monde* in 2009 (above) and 2010 (below) illustrating the animal's health conditions. The circles indicate the difference of blubber thickness in 2010.

6.4 Discussion

While within the limits of the Saguenay St. Lawrence Marine Park, humpback whales experience high levels of daily exposure. During the three years of land-based observations, 97% of the observed focal animals were accompanied by boats. Total exposure was equivalent to 78.5% of the observation time. The maximum continuous exposure lasted for almost three hours. In that occasion, the FF began before 9 o'clock a.m. and lasted until the animal left the survey area, still accompanied by boats. The extreme levels of exposure experienced by humpback whales within the marine park are not a new fact brought by the present study. However, this is the first time it was quantified.

In New Caledonia, where a population of the order of 300-400 animals concentrate during the breeding season, 54% of the observed groups were accompanied by boats (Schaffar *et al*. 2010). Within the SSLMP, on a typical summer day an average of two humpback whales are in the area (Chapter 2 and 3), and they are exposed to boats since they are found early in the morning up to the last excursion of the evening. According to the commercial zodiacs trips offer, the maximum exposure considering only boats that depart from 9 a.m. up to 6 p.m is of nine hours. As the departure of boats from each company is not synchronised, when some boats are leaving the humpback whale observation area, others are arriving. As a consequence the whale may not be exposed at the same time to a high number of boats, however, it is continuously exposed.

The average number of boats recorded around the animals' tracked from the land-based was inferior to the average recorded on board whale watching boats. The average number of boats within 1 km radius of a humpback recorded during the land-based survey was of 1.9 boats. Based on data collected on board WW boats for the same period, the average number of boats recorded within a 2 km radius of a humpback whale was of 6.4, and within 400 m was of 4 (GREMM unpublished data). The difference might be attributed to the spatial extent covered from land and on board. Land-based data are representative of the area it covers but cannot be extended to the whole study area as it does not covers, for example, important feeding aggregations as the Head of the Laurentian Channel (see chapter 3).

Most of the humpback whale exposure quantified in the present work is attributed to commercial zodiacs. At the peak of the touristic season in 2007, a maximum of 171 whale watching trips were offered per day (estimate based on the number of operating boats and their published schedules) (C. Chion, personal communication), and this number does not show much fluctuation. A total of thirty-four zodiacs (including 12, 24 and 48 passengers zodiacs) can be in the waters of the Park at the same time, departing from the three main homeports (Tadoussac, Les Bergeronnes, and Les Escoumins) (Chion *et al.* 2009). Up to 2010, there was only one 48-passenger zodiac operating within the SSLMP and from 2012 on, a second one begun to operate. Replacement of small zodiacs by bigger ones would help diminish the number of zodiacs on the water and thus whales' exposure (PMSSL 2011). Such measure, already discussed by the concerned actors in different occasions should be a priority for the SSLMP managers. In addition, a simple synchrony of departures would decrease animals' exposure by allowing them to have breaks in between the excursions.

In order to decrease individuals' exposure to whale watching activities and ensure that whales are able to fulfill their daily needs while at the SSLMP it is strongly recommended to enforce existent regulations and to discuss measures to decrease daily exposure. The simulation model recently developed in order to support management actions concerning the maritime traffic in the study area (Parrott *et al.* 2011) should be effectively used in order to build management scenarios with the whale watching industry and concerned actors. This simulation platform could be used in order to test the effect on the animals' exposure of replacing all 12 places zodiacs by 48 places, for example. In addition to a reduction of marine traffic, *no boats* areas should be created in order to provide quieter areas. Reduction of the dwelling time by observed animal within the same excursion to one period of 30 min instead of two would also be effective to reduce exposure of the main target species, which in the case of blue and humpback whales are target individuals.

The individuals of this species show high fidelity to the feeding grounds and site fidelity within the feeding grounds, which is possibly influenced by maternal transmission (Baker *et al.* 1990; Weinrich 1998; Weinrich *et al.* 2006). Once the mother returns from the breeding area with her calf of the year, the feeding area, feeding style and prey preference are transmitted (Baker *et al.* 1990; Weinrich 1998; Weinrich *et al.* 2006). A possible explanation for the low number of animals observed in the SLRE is that the animals using this feeding area were exclusively males or young animals, what kept the abundance low for a long period. The first humpback whale calf observed within the SSLMP was *Aramis*, the calf of *TicTacToe* that was first sighted in 2007 (Baleines en direct 2012). In 2012, TicTacToe was recorded in the area with another calf. Not only resident females are now at the reproductive age and will start to bring newborns to the area, as other juvenile animals were observed for long periods in the area (e.g. Perseides and Blanche-Neige, Baleines en direct 2012). In 2012 *Blanche-Neige* was recorded in the area during six consecutive months, from early in May to mid November (R. Pintiaux, personal communication).

It is in the high latitude feeding grounds that feeding takes place. The migratory pattern varies according to the age class, sex and reproductive status (Dawbin 1966; Brown *et al.* 1995) and may vary individually as well. Some animals may arrive earlier or leave later in the autumn or do not migrate at all, but while in the feeding grounds their main activity is to fulfill their energetic requirements, as little feeding activity takes place outside the feeding areas (De Sá Alves *et al.* 2009). In highly disturbed areas, as the SLRE, individual differences may play an important role for fitness.

Individual differences in behaviour, indicative of personalities, have been shown in a wide range of context and species (Dall *et al.* 2004), and there has been extensive interest in the concepts of behavioral types, behavioral syndromes, and personalities in nonhuman animal species (Dall *et al.* 2004; Koolhaas *et al.* 2010; Twiss *et al.* 2012). Individual differences constrain individuals' behavioural plasticity, and individuals often vary in the degree of behavioural plasticity they show (Koolhaas *et al.* 2010). Proactive individuals form routines readily and express little behavioural flexibility compared to reactive individuals, in which behaviour patterns are more flexible, making them more responsive to environmental stimuli (Koolhaas *et al.* 2010). Furthermore, individual variation in behavioural plasticity is likely related to rates of habituation or sensitisation to stimuli. Given that reactive individuals are those that express behavioural flexibility (Dall *et al.* 2004) one might expect reactive individuals to habituate more rapidly. Studies that take into account individual differences in behaviour are still in their infancy, a subject that offers a lack of possibilities of research in the near future.

Weinrich and Corbelli (2009) used a longitudinal database on photographically identified humpback whales from the feeding ground located off of southern New England (USA) to test the effect of exposure to whale watching vessel in calving rate (number of calves/ number of year sighted) and calf survival to age 2. No direct evidence for negative effects of whale watch exposure was observed and in some comparisons whales with more exposure were significantly more likely to produce calves and to have those calves survive to age two. However, individual differences were observed, and results suggested that animals already alive before the development of whale watching were more susceptible to impacts than younger individuals. Despite the lack of evidence for long term consequences of exposure to WW, survival was limited to the two first years of life and no mention was made to survival up to reproductive age. Besides, the higher calf production rate by more exposed animals is intriguing. Why more exposed animals invest more on reproduction than less exposed ones? Or should it be seem otherwise, animals that fail to habituate to exposure are forced to use marginal areas of the feeding site, fail to fulfill energetic requirements and are thus less prone to produce a calf or a calf in health to survive the migration from the breeding ground and to reach the second year of life? Whale watching activities in feeding areas will tend to target the densest areas, which are thus the more productive areas within the feeding ground, and animals that fail to habituate to feed with boats around may explore other patches (less interesting ones), but as consequence they are less exposed. A similar pattern was observed in Shark Bay, where animals that fail to habituate to the whale watching activity moved to another area, with direct consequences to the population abundance (Bejder *et al.* 2006). Next, the data set here analysed will be used to investigate individual differences in behaviour in the presence of boats. The lack of data in the absence of boats prevented an in depth analysis of the short-term effects of the boats presence on animal's' behaviour, but a future project intends to study this topic.

The brief historic of observations of the juvenile *Perseides* provided here, was not with the intention to suggest that the animal's health condition observed in 2010, the last year it was observed in the area, was a consequence of whale watching exposure. But, it is a good illustration of the importance to take individual differences into account. In 2009, during the focal follow conducted from Escoumins, the animal presented the highest dive intervals recorded for humpback whales along the three years of study. The animal was resting and clearly trying to avoid the boats by taking long submergences. In addition, despite its bad health conditions in 2010, the animal performed a tail-slap while two zodiacs were within 100 m of it. Tail-slap (also known as peduncle slap or tail breach depending on the energy of the behaviour) is an aggressive or treat behaviour in many cases, and it is frequently a response to harassment by boats (Clapham 2000, Personal observation). During this FF (CC100819G), which lasted 2.1 hours, the whale was accompanied by zodiacs the whole time, and in some instances, up to four zodiacs were within 100 m.

6.4.1 Conclusion

Although some authors have claimed that tourism and conservation had potential for symbiosis (e.g. Orams 1997), in much cases the relationship is one of conflict or co-existence (Higham and Bejder 2008). Whale watching is usually sold as an ecotourism activity, but at a minimum, *ecotourism is tourism which is based on the natural environment and seeks to minimize its negative impact on that environment* (Orams 1995). Much still need to be done in order to understand the real impacts of whale watching activities, however, management actions as the ones illustrated above (e.g. replacing small boats by larger ones, synchronizing trips) would approach the whale watching activity conducted within the Saguenay St. Lawrence marine park of a real ecotourism.

Chapter 7

Summary and conclusions

7.1 Key findings

The principal objective of the present thesis was to provide a better understanding of the ecology of baleen whales in the St. Lawrence River Estuary (SLRE) and to inform stakeholders' decision-making related to marine traffic management and cetacean protection within the study area. To reach these goals two main datasets were analyzed: line transect distance sampling and land-based focal-follows. A series of analyses was performed and below, a summary of the key findings elaborated in each chapter are presented.

Chapter 2- Estimating baleen whales' abundance within the marine portion of the St. Lawrence River Estuary

In this chapter the first reliable estimates of density and abundance for minke, fin, blue and humpback whales in the study area were provided. A global estimate for the period of 2006 to 2009 was obtained, as well as annual estimates for the same period. The most abundant species were minke (45, 95% CI=34-59) and fin whales (24, 95% CI=18-34), followed by blue (3, 95% CI=2-5) and humpback whales (2, 95% CI=1-4). The results were quite robust and provided base line information for the monitoring of these species in the area. Annual fluctuations were detected and reinforced the need for long-term monitoring of the species abundance to gain a better understanding of the ecosystem dynamics. The results highlighted the fragility of this system, which is composed of a small number of individuals of each species.

Chapter 3 - A spatial density model of baleen whales within the St. Lawrence River Estuary

By using generalised additive models, a spatial density model of each species in the study area was generated. The SDM allowed the identification of each species' core area as well as highlighting aspects of their habitat use patterns. The results reinforced the relevance of the proposed marine protected area (the St. Lawrence Estuary Marine Protected Area) for the conservation of essential habitats of the endangered blue whale. An extrapolation exercise was performed in order to predict blue whales' habitats outside the surveyed area. This analysis was performed only as an exploratory analysis, although the results showed a good match with independent data sets. In the lack of better information, the extrapolation exercise could guide the discussion of management measures to enhance the protection of the species within the whole marine portion of the SLRE.

Chapter 4 - Sharing the space: identifying overlaps between baleen whales' distribution and maritime traffic at the marine portion of the St. Lawrence River Estuary

In this chapter, Geographic Information System (GIS) capabilities were used to measure the degree of overlap between the navigation corridor and the resulting SDM of each species and the extrapolation model of blue whales. The analysis highlighted areas of important co-occurrence of whales and ships. The speed reduction zone recently proposed by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M) covers around 60% of the areas characterised as *high* and *very high* risk of co-occurrence. A recommendation of adjustment to the current shipping lane was suggested in order to decrease the co-occurrence in areas predicted as important habitats for the endangered blue whale.

Chapter 5 - Blue whales fine scale behavior and exposure to whale watching boats in the Saguenay-St. Lawrence Marine Park, Canada

Analysis of land-based surveys conducted from 2008 to 2010 allowed a characterisation of blue whales' exposure to whale watching activities. Blue whale data was organised by surface intervals, and the analysis showed that the animals were exposed to boats, mainly commercial zodiacs, in 74% of the 89 surface intervals (SI) under observation. Continuous exposure ranged from 2 to 19 SI and the mean number of boats within a 1 km radius was 2.3 (±2.7, max=14). On no occasion did the commercial boats observe the legal distance to approach endangered species (400 m) and in 22.5% of the SIs they were within 100 m of the focal-animal. Additionally, individual blow rate variance was correlated with percentage of exposure to boats (0.73, $p<0.05$).

Chapter 6 - Exposure of humpback whales to whale watching activities in the Saguenay-St. Lawrence Marine Park – Quebec, CA

As for blue whales, data collected during the same period of land-based surveys, was used for a similar analysis to characterise humpback whales' exposure. However, instead of considering the surface interval as the sample unit, the whole observation period was used. This choice was based on the difference of behaviour of the species and of the boats around it. Within the study area, blue whales are eating most of the time and spend little time on the surface in between long dives (8.5 min ±2.2). Boats usually won't stay around a blue whale for more than a few surface periods (and in between them, boats might need to approach the animal again). Humpback whales do not present such long dive periods and boats in interaction with the species will stay longer and can easily keep their position around the animal.

A total of 50.4 hours of humpback whales observation was analyzed. Whales were exposed to boats, mainly commercial zodiacs, during 78.5% of the observation time. The mean number of boats within a 1 km radius was 1.9 (±2.3, max=22). Continuous exposure of the same individuals emerges as a consequence of multiple factors, such as: the reduced number of animals in the area, the attractiveness of the species for whale watching activities, lack of synchrony of trip schedules among the companies established within the marine Park and the relatively long observation time allowed by the marine regulations.

7.2 Limitations and future work

During this work some limitations were encountered.

i. The dimensions of the study area precluded the inclusion of dynamic variables in the spatial density model. In situ data were not collected during the line transect surveys and a circulation model for the estuary was not available at an appropriate spatial resolution. In addition, available environmental data from satellite imagery are generally at a coarser resolution for the analyses performed here.

ii. The opportunistic nature of whale - boat interactions in the present study made it impossible to perform before-during-after (BDA) experiments to further investigate the factors that possibly influence animals' behavior (*e.g.* number of boats, their distance, their geometry around the whale, their position in relation to the animals' path).

iii. In addition, periods of data collected without boats were too short to allow comparing focal species' behaviour in the presence and absence of boats

iv. The low height of the land-based stations limited the surveyed area to the near shore zone. Higher platforms would allow extending the survey area up to five nautical miles.

In terms of future work, the following points should guide further investigations:

i. ***Regarding baleen whales ecology***

- Analyse line transect distance sampling data collected in 2010 and 2011 following the parallel design. These data may improve the spatial density model results due to their wide coverage over the southern cliff. In addition, they might improve abundance and density estimates as they incorporate a larger portion of the Laurentian Channel Head;

- Establish a collaboration with the group of J. F. Gosselin and colleagues, which conduct line transect distance sampling over a contiguous study area, to conduct a unified analysis of the distance sampling data and obtain density and abundance estimates over a larger extent;
- Develop correction factors based on the baleen whales' breathing pattern to correct the abundance estimates;
- To deal with data overdispersion, investigate the improvements of using a Twedi distribution (Williams *et al*. 2011) or of splitting the modelling process in two stages by using zero-inflated models (Zurr *et al*. 2009);
- Compare variance estimates using non-parametric bootstrapping with moving block boot-strap, which allows accommodating the correlation between counts of segments close in space and time (Clarke *et al*. 2003);
- Monitor baleen whales (minke, fin and humpback whales) diet over time using biopsy samples. Annual samples, in addition to acoustic sampling of prey species (currently ongoing in the study area), would allow a better understanding of the species' diets and of the ecosystem dynamics across the time;
- Investigate the factors guiding the intra-annual temporal fluctuations of whales densities within the study area by considering dynamic variables and, if possible, prey species;
- Conduct fine scale analysis of baleen whales' niche partition using multiple data sets (horizontal niche partition), and investigate the vertical niche partition using VHF tracking methods;
- Investigating minke whales' social structure over different spatial scales would improve our knowledge of the species' behaviour with possible direct implications for the methods used to derive population parameters such as density and abundance;
- Include fin whales' group size in future modelling exercises in order to improve model robustness;

ii. Regarding the overlay with the navigation corridor:

- Apply the method developed by Erbe *et al*. (2012) based on Automatic Identification System (AIS) data to derive large-scale noise maps for the SLRE;
- Conduct passive acoustic monitoring experiments to characterise the levels of noise pollution in different areas within both MPAs, providing the necessary support to include noise levels as a parameter in costal zoning;
- Increase the extent of systematic surveys including portions of the SLEMPA (see example in Chapter 2) and of the 200 m bathymetric contour to validate the results of the extrapolation exercise of blue whales' distribution and further assess the adequacy of the suggested adjustment to the Traffic Separation Scheme;
- Establish a collaboration with the shipping industry and design a survey using ships as platforms of opportunity (e.g. Williams *et al.* 2006) in order to gather systematic data over a larger spatial extent (marine portion of the SLRE and coastal portion of the GSL) that will allow to extend the analysis of co-occurrences between cetacean species and the maritime traffic up the Gulf of St. Lawrence (GSL);

iii. Regarding land-based behavioural studies:

- Design before-during-after experiments, in collaboration with the whale watching industry, to investigate the short-term effects of whale watching boats on animal's behaviour and provide support to improve the management of the activity as part of the adaptive management framework;
- Investigate compliance using the existent database (e.g. humpback whales) and compare it to the period after the creation of the *Aliance Eco-Baleine (*an alliance of whale-watching companies formed in 2011 which has developed an industry-defined code of conduct);
- Analyse the existent data based on humpback whales to characterise breathing patterns and activity budget, if possible, taking individual differences into account.

- Design a study to characterise the exposure of baleen whales to kayaks and provide support for a better management of the activity within the marine park.

7.3 Summary and conclusions

The St Lawrence River Estuary is a unique ecosystem. It supports a great diversity of habitats and species, and a high diversity of marine mammal species, usually found exclusively in more remote areas (e.g. Arctic, Antarctic). The Saguenay St. Lawrence Marine Park (SSLMP) is known as one of the best places to whale watch in the world (Scarpaci *et al.* 2008). Its diversity of landscapes contributes to the beauty and attractiveness of the area. However, as has been shown in the present work, the SLRE is also a fragile ecosystem.

Only a few individuals of each of the baleen whale species use the area, but for these animals this ecosystem is essential. They are seasonal residents, but have been for many decades each and for many generations. Due to the rapid development of eastern North America over the past two centuries and the intense use of coastal habitats, their feeding ground is now highly exposed to the effects of intense maritime traffic. A navigation corridor crosses their core habitats with an intrinsic collision risk and contributing to the overall noise pollution of the area. In addition, whales' exposure to whale watching is of concern as a consequence of the activity of a well developed industry, which is completely dependent on the whales' presence and well-being.

Effective management measures to enhance baleen whales' protection within the study area are urgently needed. The present study represents an important step towards effective conservation. Important core areas for the baleen whales were identified within the already existent marine protected area (MPA), in addition, substantial quantitative support for the creation of the St. Lawrence Estuary Marine Protected Area was provided. However, the sole existence of MPAs is not enough to ensure the protection of these species and their habitats. Clear and scientifically sound management and zoning plans are essential to achieve conservation success within MPAs. The Marine Park and the proposed

MPA have the potential to become a model for the maintenance of biodiversity and of sustainable management of marine resources and human activities, a key goal of the Saguenay St. Lawrence Marine Park (PMSSL 2010). However, to date, the management plan of the SSLMP lacks clarification with regards to its role on baleen whales' protection. What are the goals to be followed by the SSLMP in terms of conservation of whales? What is it meant to achieve?

Certainly, the adoption of the Marine Mammals Regulation for whale watching activities within the Marine Park was an important step toward whales' conservation. The regulation is the only one to date in Canadian waters. However, as has been demonstrated, compliance is not the rule, even for the most endangered species. The Marine Park zoning plan constitutes another important instrument for the sound management of the area and to enhance marine mammals' protection.

The SSLMP is in the process of establishing its zoning plan (PMSSL 2010), and a first version of it was available for consultation but is not yet under application. Despite the large areas identified as priority for conservation presented in the Ecosystems Conservation Plan of the SSLMP (Dionne 2001), the status of "integral protection" was only attributed to a few small areas, some of which were designated to enhance visitors experience while conducting land-based whale watching. No effective measure to enhance cetacean's habitat protection was contemplated in the zoning plan.

Based on the results presented here, two zoning measures are suggested to fulfill this gap. The first one, introduced in Chapter five, was to limit speed within one nautical mile from the north shore to 10 knots. This measure was proposed and discussed during a public meeting held during the fall of 2009 but, at the time, it was not retained due to a lack of scientific support. Here, the scientific support necessary is provided. Figure 77 illustrates the proportion of the baleen whales' core area that would be encompassed by this measure, which would benefit other marine mammal species as well. In addition, this measure almost completely overlaps with the speed reduction zone recently recommended to the large shipping industry.

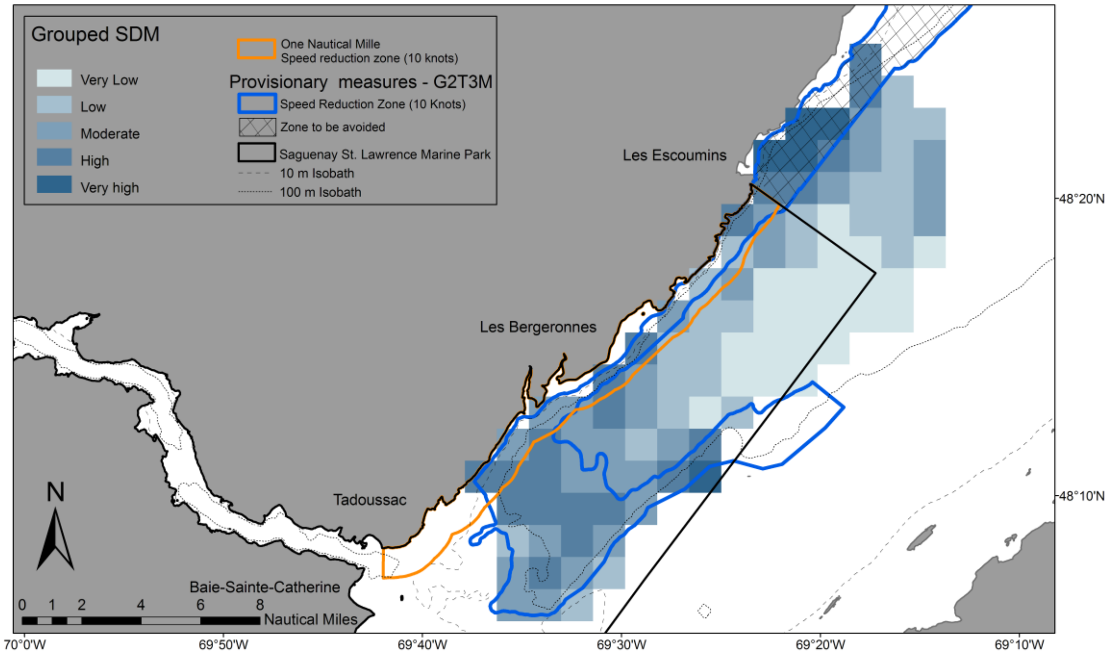

Figure 77. Suggested speed reduction zone, baleen whales' core areas and the provisionary measures recommended by the working group on marine mammals and maritime traffic (*Groupe de travail sur le traffic maritime et les mammiferes marins* G2T3M).

In addition to decreasing collision risk, a speed reduction would further improve public experience, a topic that was not in the scope of the present work, but that deserves special attention in the Marine Park. By going slower, the whole experience would be enhanced (Figure 78). Whale watchers are seeking an ecotourism experience. Those who are looking for the experience of a fast boating trip should not select whale watching. There are many other features of the environment that can be appreciated from the water, if you navigate slow enough to allow their observation. Besides, many whale watching opportunities are lost, as the boats pass quickly by an area (Personal observation). By increasing the time spent searching in the same area, pilots' may diversify excursions, decrease the pressure on the animals' that are usually tagged, inhibit the formation of dense boat aggregations and reduce noise production.

Figure 78. The amazing experience of observing a humpback whale (Aramis) in the wild (Photo: Cris Albuquerque Martins).

The second measure, an extension of the land-based whale watching zone, intends to decrease whales' exposure within an important core area, increase whale watching experience from land-based viewpoints, provide a secure area for kayaks and improve general navigation security (Figure 79). Within the marine Park, Land-based whale watching (LBWW) is possible from some points along the north shore. The activity is also offered from the Interpretation Center of *Cap Bon Désir* and is practiced from *Paradis Marin* and *Mer et Monde* Camping Grounds (Figure 80). To enhance Interpretation Center visitors' experience, the SSLMPA zoning plan established an integral protection zone in front of the cap (Figure 79). The limit of this zone was increased to encompass the area within one nautical mile from the shore line along three nautical miles. This measure would provide the first portion within the Marine Park without motorised boats.

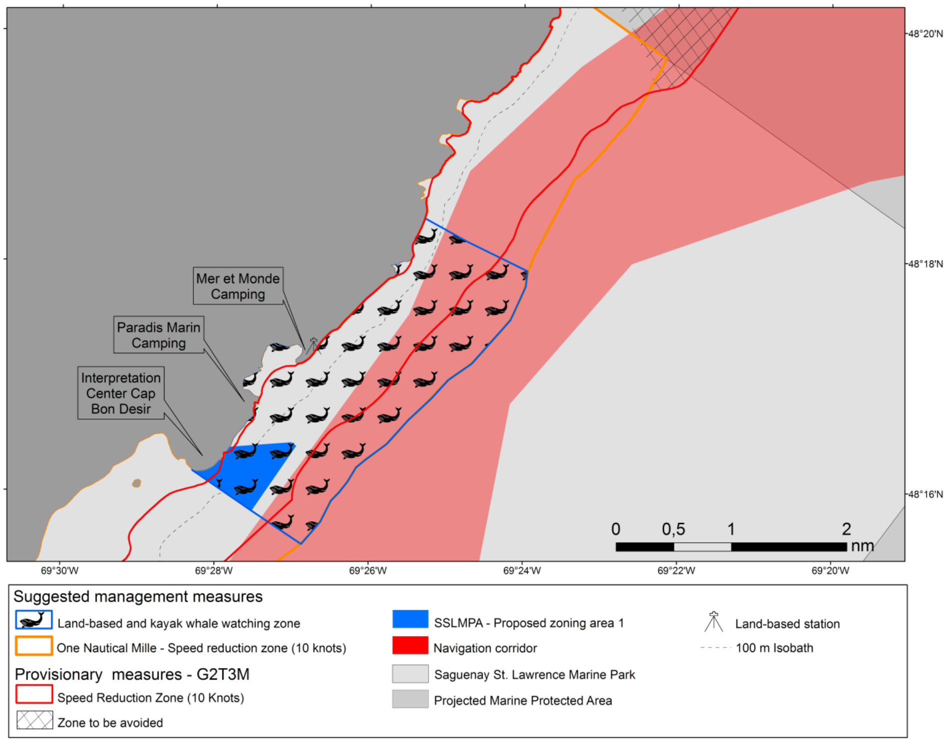

Figure 79. Suggested management measure to increase land-based and kayak whale watching experience, enhance security and decrease whale exposure within an important core area.

The suggested zone encompasses the whole area used for LBWW and provides an exclusive territory for kayak activities. The main accesses to the water for kayaks are from the two camping grounds above mentioned, which offer guided excursions as part of their activities (Figure 81). Besides, experienced users usually benefits from the facilitated access to the water offered in these two locations. It was estimated that a total of 35 650 kayak trips occur within the Marine park annually (PMSSL 2010).

Figure 80. Land-based whale watch of a blue whale from the Paradis Marin Camping ground (Photo: Cris Albuquerque Martins).

Figure 81. Humpback whale (Petit prince) passing by a group of Kayaks in front of *Mer et Monde* camping ground showing the usual configuration of kayaks accompanied by a guide (Photos: Pauline Gauffier).

LBWW is an amazing activity that is only possible in few locations around the globe (e.g. southern right whales from Puerto Pyramides – AR and from Guarda do Embau – BR). The SSLMP offers a unique opportunity for LBWW of multiple cetacean species: blue whales, fin whales, humpback whales, minke whales, beluga whales, porpoises and seals can all be observed from the land. The activity attracts 760853 people annually, while sea tours attract 283836 (PMSSL 2010). In addition to the percentage of public it attracts, the activity does not have any impact on the observed animals.

The management plan of a marine protected area should incorporate multiple-uses, and it would be natural to have an area designated for LBWW and kayak users. As was shown in Chapter 6, there were a high number of co-occurrences between humpback whales and kayaks in the surroundings of the *Mer et Monde* camping ground. An in depth study should be conducted in order to quantify the possible impacts the activity might have on the cetacean species that use the area, provide insights for better management of the activity, and to determine carrying capacity. The maximum number of kayaks observed during the three years of field-work was 46 and it was recorded during the construction holidays, a week that is characterised by the highest numbers of tourists in the region. To date, no incidents involving kayaks, zodiacs and whales was recorded, but in some instances, the whale must choose carefully where to surface to breathe (Figure 82). In addition to kayaks and zodiacs, as illustrated in Figure 83, this area is also at the vicinity of the commercial shipping pilots station, and is crossed by all boats going up and down the estuary that need a pilot on board.

Figure 82. Focal-follow (01/08/2010) of a humpback whale conducted from *Mer et Monde* camping ground showing a high concentration of boats (zodiacs and kayaks) in the area and the lack of maneuverability for the whale (Photos: Pauline Gauffier).

Figure 83. Pilots boat approaching a container to go onboard and accompany it upstream the St. Lawrence River Estuary up to Quebec (Photo: Cris Albuquerque Martins).

In conclusion, there is a worldwide call for MPAs which include marine mammal species to include effective conservation measures as part of their management plan strategy. These long living animals have been using the ocean since long before human societies evolved. An essential part of their life cycle depends on areas of high productivity, such as the SLRE. Although not spending the whole year in the area, these animals are residents of the area during an important part of the year, a crucial time for them. And they return year after year for several decades. As scientists and managers, we are reaching the point where all the basic knowledge necessary for sound ecosystem-based management is available. It is time to put this knowledge in practice.

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Annexes

Annexe 1. Code used to fit the generalised additive model (Chapter 3)

```
#open data

sdm2km=read.table(file.choose(), header=TRUE)

#c:spatial_data/SDM/sdm2km.txt

summary(sdm2km)

library(AED)

Physics_cor=cbind(sdm2km[,9],sdm2km[,10],sdm2km[,21],sdm2km[,24],abs(sdm2km[,25]),sdm2km[,28],sdm2km[,29])

colnames(Physics_cor)=c("Longitude","Latitude","Slope","Slope_SD","Depth", Depth_SD", "Coastline_distance")

pairs(Physics_cor, lower.panel = panel.smooth22,upper.panel = panel.cor2, diag.panel = panel.hist)

corvif(Physics_cor) # values (GVIF) must be below 3, no collinearity
```

```
#model fit

library(mgcv)

ba.sqrtk8=gam(ba~(log(2*Length/1000*1.4*0.3346))+s(Longitude,k=8)+s(Slope_SD,k=8)+s(sqrt(abs(Depth)),k=8)+s(Coastline_distance,k=8),family=quasipoisson(link="log"),gamma=1.4,data=sdm2km)

summary(ba.sqrtk8)
```

```
#gam plot
```

```
x11()
par(mfrow=c(2,2))
plot(ba.sqrtk8,shade=TRUE,seWithMean=TRUE,scale=0)
#gam check
x11()
gam.check(ba.sqrtk8)
#prediction grid
ba_pred=read.table(file.choose(), header=TRUE)
#open prediction grid
dim(ba_pred)
ba_pred=predict.gam(ba.sqrtk8, ba_pred, type="response")
max(ba_pred)
ba_bind=cbind(ba_pred,as.matrix(ba_pred))
head(ba_bind)
library(gstat)
coordinates(ba_bind)=~Longitude+Latitude
library(rgdal)
map=readOGR(dsn="C:/ArcGIS",layer="saint_laurent")
bathy=readOGR(dsn="C:/ ArcGIS",layer="bathy_100m")
proj4string(ba_bind)="+proj=utm +zone=19 +ellps=GRS80 +datum=NAD83 +units=m
+no_defs +towgs84=0,0,0"
bubble(ba_bind,zcol=14,col="red",
sp.layout=list(list("sp.polygons",map,fill="blue"),list("sp.lines",bathy,col="white")))
```

#Density and abundance

```
sum(ba_pred)
max(ba_pred)
min(ba_pred)
#density of groups
Dbag=(ba_pred/4)
max(Dbag)
min(Dbag)
mean(Dbag)
#density of individuals
Dba=(ba_pred/4)*1.03
#1.03 is the mean group size for minke whales
max(Dba)
min(Dba)
mean(Dba)
N_ba=sum(ba_pred*1.03)
N_ba
####Export prediction
head(ba_bind)
head(ba_pred)
write.table(ba_bind, file = "ba_pred.csv", sep = ",", col.names = TRUE,qmethod = "double")
```

#Bootstrap

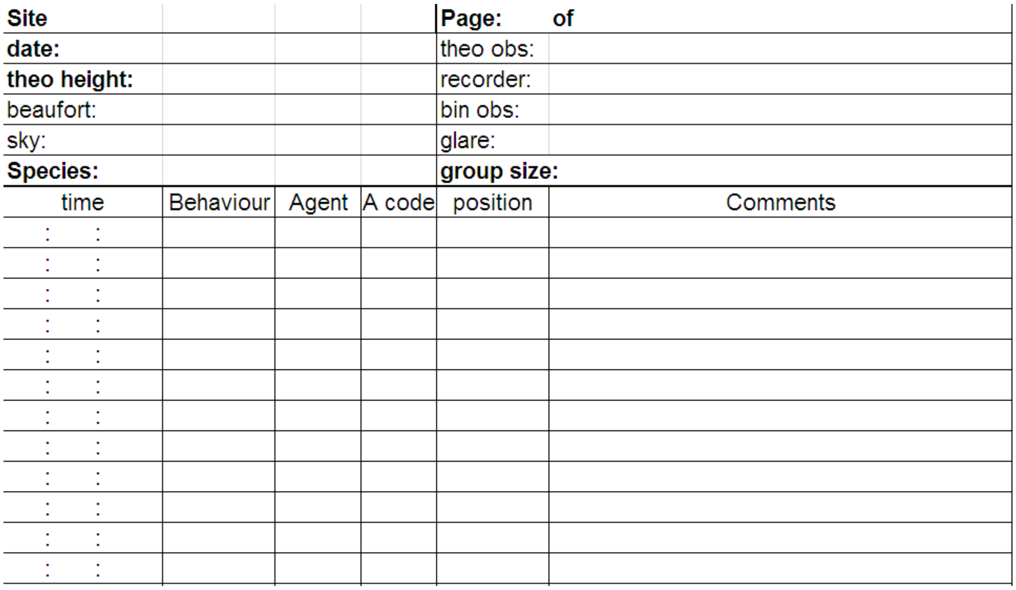
```
sdm2km=read.table(file.choose(),header=TRUE)#c:/spatial data/SDM/sdm2km.txt
pred_ba_2km=read.table(file.choose(), header=TRUE)# prediction grid
sdm2km_ba=sdm2km
list_transect=as.matrix(unique(sdm2km_ba[,"Date"]))
result=matrix(0,123,1)
for(i in 1:1000){
	sdm2km_ba_subset_final=matrix(0,0,0)

	for(i in 1:nrow(list_transect)){

	random=sample(1:nrow(list_transect),1,replace=T)
	date_random=list_transect[random]

	sdm2km_ba_subset=subset(sdm2km_ba,sdm2km_ba[,"Date"]==date_random)
	sdm2km_ba_subset_final=rbind(sdm2km_ba_subset_final,sdm2km_ba_subset)

	}
	ba.gam=gam(ba~(log(2*Length/1000*1.4*0.3346))+s(Longitude, k=8)+s(Slope_SD,k=8)+s(sqrt(abs(Depth)),k=8)+s(Coastline_distance,k=8),family=quasipoisson(link="log"), gamma=1.4,data=sdm2km_ba_subset_final)
	ba_pred_2km=as.matrix(predict.gam(ba.gam, pred_ba_2km, type="response"))
	result=cbind(result,ba_pred_2km)
```

```
}
result_ba= subset(result, select = -1 )
#Density
result_ba_D=result_ba/4
min_D=as.matrix(apply(result_ba_D,2,min))
max_D=as.matrix(apply(result_ba_D,2,max))
mean_D=as.matrix(apply(result_ba_D,2,mean))
colnames(min_D)="Minimun"
colnames(max_D)="Maximum"
colnames(mean_D)="Mean"
Density=cbind(min_D,max_D,mean_D)
#Coefficient of variation for each cell
cell_CV=as.matrix((apply(result_ba_D,1,sd))/(apply(result_ba_D,1,mean)))
colnames(cell_CV)="CV"
CV_pred_ba_2km=cbind(pred_ba_2km,cell_CV)
coordinates(CV_pred_ba_2km)=~Longitude+Latitude
#plot CV
library(rgdal)
map=readOGR(dsn="C:/ ArcGIS",layer="saint_laurent")
bathy=readOGR(dsn="C:/ ArcGIS",layer="bathy_100m")
proj4string(CV_pred_ba_2km)="+proj=utm +zone=19 +ellps=GRS80 +datum=NAD83 +units=m +no_defs +towgs84=0,0,0"
```

```
bubble(CV_pred_ba_2km,zcol="CV",col="red",
sp.layout=list(list("sp.polygons",map,fill="blue"),list("sp.lines",bathy,col="white")))
#Export prediction
head(pred_ba_2km)
head(CV_pred_ba_2km)
write.table(CV_pred_ba_2km, file = "CV_pred_ba_2km.csv", sep = ",", col.names =
TRUE,qmethod = "double")
#Coefficient of variation of density estimates
CV_D=sd(mean_D)/mean(mean_D)
#Abundance
N_ba=as.matrix(apply(result_ba*1.04,2,sum))
colnames(N_ba)="Abundance"
#Graph, outliers are not shown
par(oma=c(0.5,0,0,0))
par(mfrow=c(1,2))
boxplot(Density[,3], main="Density of minke whales",ylab=expression(paste("Density
(whales/km"^(SOR/2002-76),")")), outline=FALSE)
boxplot(N_ba, main="Abundance of minke whales",ylab="N", outline=FALSE)
mtext("Bootstrap - 1000 iterations",side= 1,outer=TRUE,line=-3)
# Autocorrelation of residuals
library(mgcv)
ba.sqrtk8=gam(ba~(log(2*Length/1000*1.4*0.3346))+s(Longitude, k=8)+s(Slope_SD,
k=8)+s(sqrt(abs(Depth)),k=8)+s(Coastline_distance,k=8),family=quasipoisson(link="log"),
gamma=1.4,data=sdm2km)
```

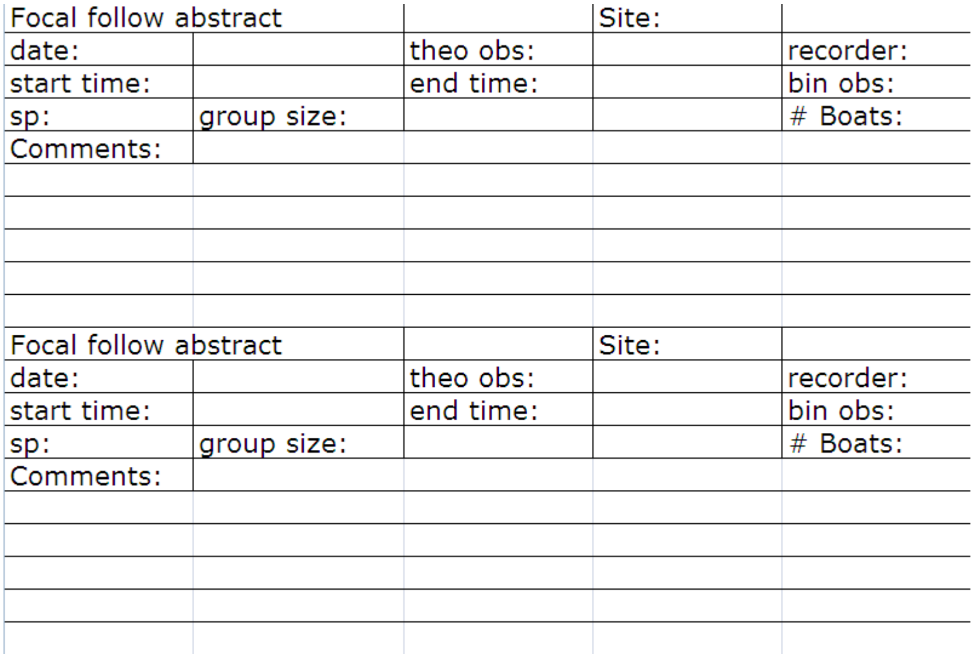
```
summary(ba.sqrtk8)

library(geoR)

ba_residu=as.matrix(residuals(ba.sqrtk8))

colnames(ba_residu)="residual_value"

ba_residu_sp=cbind(sdm2km[,c("Longitude","Latitude")],ba_residu)

library(gstat)

coordinates(ba_residu_sp)=~Longitude+Latitude

ba_residu_geo=as.geodata(ba_residu_sp,data.col="residual_value")

#max.dist is the distance up to which you want to see if there is spatial correlation

ba.variog=variog(ba_residu_geo,max.dist=15000)

ba.env=variog.mc.env(ba_residu_geo,obj.variog=ba.variog,nsim=400)

plot(ba.variog,envelope=ba.env)
```

Annexe 2. Spreadsheet used for data collection during land-based survey



Site				**Page:**	**of**
date:				theo obs:	
theo height:				recorder:	
beaufort:				bin obs:	
sky:				glare:	
Species:				**group size:**	
time	Behaviour	Agent	A code	position	Comments
: :					
: :					
: :					
: :					
: :					
: :					
: :					
: :					
: :					
: :					
: :					
: :					

Figure 84. Spreadsheet used in the field during land-based station data collection.



Focal follow abstract			Site:	
date:		theo obs:		recorder:
start time:		end time:		bin obs:
sp:	group size:			# Boats:
Comments:				
Focal follow abstract			Site:	
date:		theo obs:		recorder:
start time:		end time:		bin obs:
sp:	group size:			# Boats:
Comments:				

Figure 85. Daily abstract spreadsheet used to have an overview of the data collected each day.

Annexe 3. Land-based data analysis protocol

How to Start the Total Station in the Field:

1) Press “ON”
2) Under the “Menu” screen, use the arrow buttons to set the horizon (hz)
3) Enter horizon coordinates for that specific site – Bearing to reference object (see table 1).

Table 26. Observation sites’ locations and bearing to reference object.

Location	Code	Latitude	Longitude	Height	Bearing
Bergeronnes	CC	-69,541999	48,230783	16,102	**221 36 50**
Reference	Haut Fond prince	-69,619704	48,1094		
Mer et Monde	MM	-69,446003	48,28668	18,343	**231 37 30**
Reference	Haut Fond prince	-69,619704	48,1094		
Mer et Monde	MM	-69,446003	48,28668		
Reference	Phare Bon Désir				**226 20 53**
Point noire	PN1	-69,717287	48,123157	38,305	**102 23 16**
Reference	Haut Fond prince	-69,619704	48,1094		
Point noire	PN2	-69,716706	48,1229	33,9	**102 14 53**
Reference	Haut Fond prince	-69,619704	48,1094		
Escoumins	ES	-69,392273	48,336009	13,431	

4) Verify that the cross in the Theodolite is in the correct position on the reference object
5) The screen will say “Enter to Hold”--Press “enter”
6) The screen will say “Enter to release”—Again, verify that the Theodolite cross is in the correct position on the reference object and press “enter”

7) Press “PTNR” to change location name and number (PTNR also changes from letters to numbers and vice versa)
8) Name the site (CC0001,MM0001, PN10001 or PN20001) press “enter”
9) Measure the height of the Theodolite
10) Enter height under “hr”
11) Press “enter” and “enter”
12) If above is done correctly, the screen will show the code and number of the position typed in “PTNR” and the coordinates of the reference object
13) Set the cross in the Theodolite to the reference object (lighthouse, island etc.)
14) Press “REC” making the reference object the first recorded entry (ex. MM0001)
15) Check the level bubble to ensure the Theodolite is straight regularly.

How To Download Data from the Total Station:

1) Connect computer cable to the Leica Station. Line up the red dot on the cable with the red dot on the station.

2) Open the program “TCTOOLS”

3) Using the arrows on the computer keyboard, select “Recevoir” under the **Transfert Donnees** menu → Enter → Select “Mesures” → Enter

4) At the bottom right corner of the screen there should be a column flashing called “Enreg. Fichier”, type the date of the data in ddmmyy format → Enter

5) A red window called **Message** will appear, select “Choisir Format” → GSI mask 1 → Enter

**Note: This step will cause the station/computer to make some noise, don’t be afraid! It could take a while.

6) Once the data is finished downloading into the computer, a red box will appear and say “Message” → Enter → Esc

7) In the **Transfert Donnees** menu select “Sortie du programme” → Enter → Enter

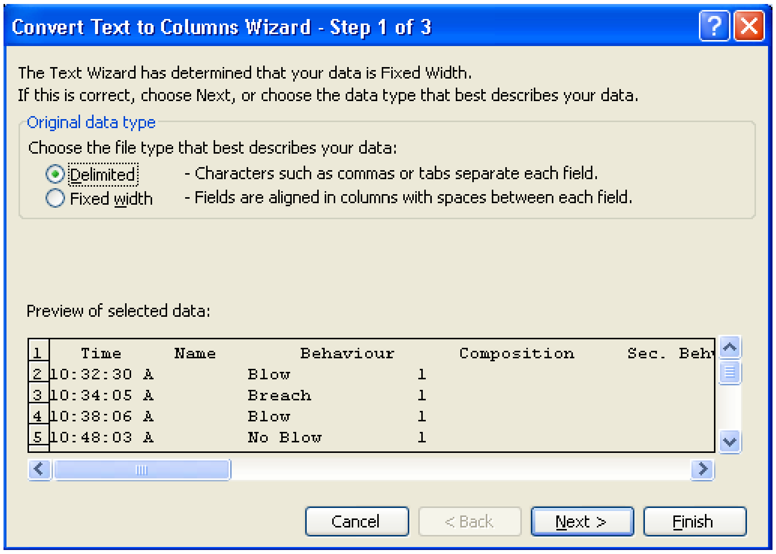
8) Verify that the data was successfully downloaded into the computer → My Computer → C: Drive → TCTOOLS. The file should be the first .txt file at the top of the list. It will be called ddmmyy.txt

9) Once the data is verified, delete the file from the total station. TCTOOLS → Select "Effacer sur TC" under the **Transfert Donnees** menu → Enter → Mesures → Enter.
A red box will appear → Enter. Another red box will appear saying "Message Deleted". → Enter

10) Close TCTOOLS by selecting "Sortie du programme" in the **Transfert Donnees** menu → Enter → Enter

How To Prepare the file to Cyclops:

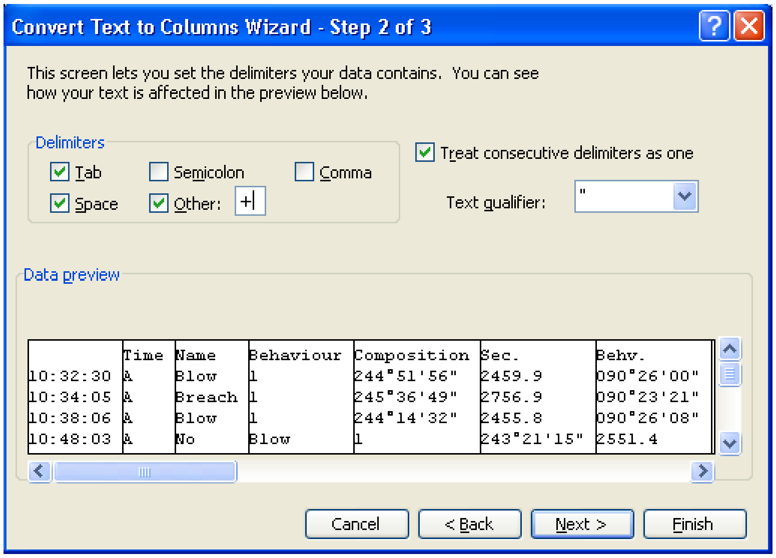
1) Open Excel → Select the Open folder button → Select your .TXT file (it can usually be found in My Computer → C: Drive → TCTOOLS). A series of messages will appear. To enter the data into columns, select "Delimited" in the **Convert Text To Columns Wizard – Step 1 of 3** window → "Next" → Select "Tab" and "Space" and "Other" (type +) in the **Convert Text to Columns Wizard 2 of 3** window → "Next" → Select "Finish" in the **Convert Text to Columns Wizard 3 of 3** window



The Text Wizard has determined that your data is Fixed Width.
If this is correct, choose Next, or choose the data type that best describes your data.

Choose the file type that best describes your data:
● Delimited - Characters such as commas or tabs separate each field.
○ Fixed width - Fields are aligned in columns with spaces between each field.

```
1    Time      Name         Behaviour       Composition      Sec. Beh
2 10:32:30 A          Blow           1
3 10:34:05 A          Breach         1
4 10:38:06 A          Blow           1
5 10:48:03 A          No Blow        1
```



This screen lets you set the delimiters your data contains. You can see how your text is affected in the preview below.

Delimiters

☑ Tab ☐ Semicolon ☐ Comma
☑ Space ☑ Other: +

☑ Treat consecutive delimiters as one

Text qualifier: "

Data preview

	Time	Name	Behaviour	Composition	Sec.	Behv.
10:32:30	A	Blow	1	244°51'56"	2459.9	090°26'00"
10:34:05	A	Breach	1	245°36'49"	2756.9	090°23'21"
10:38:06	A	Blow	1	244°14'32"	2455.8	090°26'08"
10:48:03	A	No	Blow	1	243°21'15"	2551.4

p.s.: If the file is already opened Click on the "A" in the first row of the spreadsheet so that the entire column is highlighted blue→ Select **Data** from the menu at the top of the screen and highlight "Text to Columns" → Select "Delimited" in the **Convert Text To Columns Wizard – Step 1 of 3** window → "Next" → Select "Tab" and "Space" and "Other" (type +) in the **Convert Text to Columns Wizard 2 of 3** window → "Next" → Select "Finish" in the **Convert Text to Columns Wizard 3 of 3** window

2) That's how the data from the total station looks like:

	Location		**Horizontal**		**Vertical**							**Station**		
	code		**angle**		**Angle**							**height**		
110001	**MM001**	21.124	**23137280**	22.104	**9006360**	31...0	0	51..0.	10	0	87..00	**1535**	88..00	0
110002	**MM002**	21.124	**14557330**	22.104	**9823450**	31...0	0	51..0.	10	0	87..00	**1535**	88..00	0

* First identify the desired columns (in bold), and delete all other columns.

Location code	**Horizontal angle**	**Vertical Angle**	**Station height**
MM001	**23137280**	**9006360**	**1535**
MM002	**14557330**	**9823450**	**1535**

4) Insert new columns after the horizontal and vertical angle columns and divide each of them by 100,000. These are the new horizontal and vertical angle columns.

Location	Horizontal	**Horz.**	Vertical	**Vert.**	Station

code	angle	**Angle**	Angle	**Angle**	height
00MM0001	23137280	**231.3728**	9006360	**90.0636**	1535
00MM0002	14557330	**145.5733**	9823450	**98.2345**	1535

5) If the file has data from two different sites, copy and paste all positions from one site in separate files into a new excel file. Save each file as an excel file (.xls) using the location code and date and height of the total station as the name of the file (ex. CCyymmdd_1610).

6) Add: date, time, name, behaviour, composition, secondary behaviour and comments columns → fill in from notes taken in field (columns' names should be typed always in the same way – see point 7).

7) The columns of each text file should be exactly as follows:

Date	Time	Horz Angle	Vert Angle	Name	Behaviour	Composition	Secondary Beh.	Comments

**Make sure that the date is in DD/MM/YY format in excel. Use English (Caribbean)

8) The file is ready to be filled with data from the field.

BE CAREFUL WHILE FILLING IN THE FILE WITH FIELD DATA!

1) Be sure that the information is in the good columns (all spaces must be replaced by "_". Also, be sure tat the last column was imported correctly.
2) Be sure that whale behaviours were not assigned to boats.
3) Add the fields:
    a. Date (with the day of file you are working on)(yyyy-MM-DD)
    b. At this point the Agent_id column does not exist, and all information regarding it is on "Name" and "Comments" column. All agents must be assigned a letter (marine mammals) or a number (boats) in the column "Name" and its type should be specified at the column "Comments". Follow the codes bellow in the field and while transcribing data:

Agent_id	Agent_name
ba	Minke whale
bp	Fin whale
bm	Blue whale
mn	Humpback whale
dl	Beluga
pm	Sperm Whale
pp	Harbor Porpoise
s	Seal sp
la	Dolphin sp
z	Zodiac
g	Big excursion boat
pl	personnal boat
c	cargo boat
k	Kayak
au	other
uk	unknown
f	Ferryboat

<u>How to Enter a Text File into Cyclops:</u>

1) Open Cyclops
2) File → Project → Select Project → Select location of focal follow
3) File → Create Job → Set focal follow date
4) A window called "Open IMPORT Text File" will appear → Select the desired focal follow .txt file
5) Select "New Obs" → Station Info. → Enter the height of the total station on the date of the follow and the time the follow began

6) Select “Settings” → Input Text Fields → Select the formats of your .txt file. Date should be DD/MM/YY, time should be HH:MM:SS, angles should be aa.mmss
7) Select “Test” → Select your .txt file. The test box should show the correct data in each column; if this data is ok press “OK”
8) If there are problems, there are several things that could be wrong:

- The excel file could have commas instead of periods in the angle column
- The excel file could have improper Date of Time format
- There could be blank spaces in the excel file (delete or fill in, if this is the case)
- If there are still problems, select Settings → Input Text Fields, and re-select your file. You can always close cyclops and start again. Be patient it is just software!

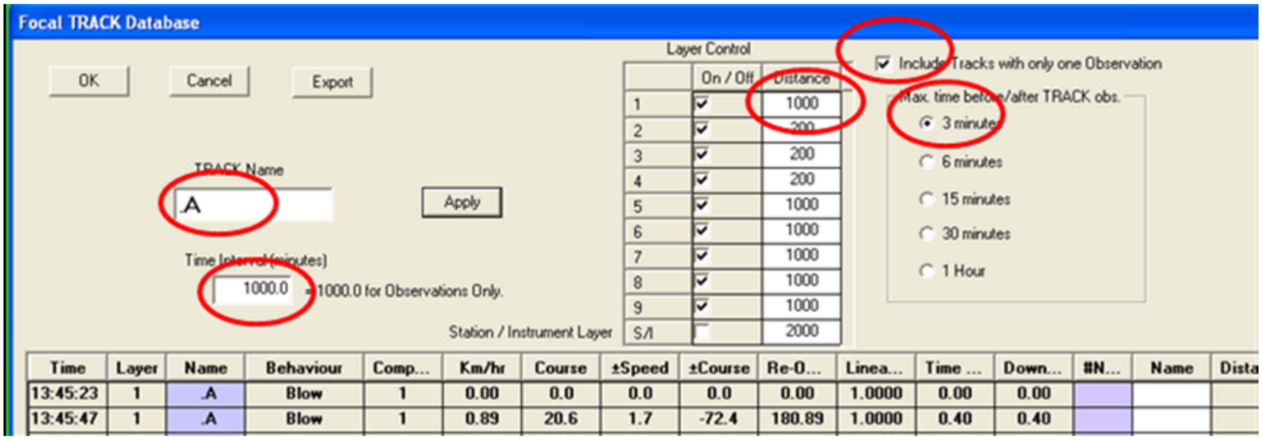
9) If everything is ok, press “Space”→ positions should start appearing. If anything looks wrong (positions are on land, time or date incorrect etc.) close cyclops and start again. As each position enters, check the data to see if all fields are filled.
10) Once .txt file has been entered, select “Database” → Observation Database → Export
11) Database→ Focal Tracks Database → Export. Close Cyclops. You have now 2 .csv file.
12) Open Cyclops Folder → Folder of site location (CC, MM,…)→ GIS Folder → Create a new folder with the name CCyymmdd.
13) Open the .csv files you created in step 10. They are located in Cyclops → Site Folder (CC, MM, etc.). Change the observation database file name to CCyymmdd_final. Save them in Excel format inside the folder you created in step 10.

Methodology: From field data to GIS:

Needed files :

- ✓ .csv (the observations database in Cyclops (Cyclops output))
- ✓ Focal database (files .cvs, other output of Cyclops). For the parameters we use a maximum distance of 1000m, a maximum time before/after track = 3

minutes, we included the tracks with only one observation and we set the time interval at 1000. If there is more than one animal observed (for 30 minutes minimum) in the same file, we need several outputs : one for each animal.



Focal TRACK Database

TRACK Name: .A

Time Interval (minutes): 1000.0 =1000.0 for Observations Only.

☑ Include Tracks with only one Observation

Max. time before/after TRACK obs.
● 3 minutes
○ 6 minutes
○ 15 minutes
○ 30 minutes
○ 1 Hour

Layer Control

	On / Off	Distance
1	☑	1000
2	☑	200
3	☑	200
4	☑	200
5	☑	1000
6	☑	1000
7	☑	1000
8	☑	1000
9	☑	1000
S/I	☐	2000

Station / Instrument Layer

Time	Layer	Name	Behaviour	Comp...	Km/hr	Course	±Speed	±Course	Re-O...	Linea...	Time ...	Down...	#N...	Name	Dista
13:45:23	1	.A	Blow	1	0.00	0.0	0.0	0.0	0.00	1.0000	0.00	0.00			
13:45:47	1	.A	Blow	1	0.89	20.6	1.7	-72.4	180.89	1.0000	0.40	0.40			

<u>Stages:</u>

1) **Change (one or several) data like xxx_FOCAL.csv. (with excel)**

   a. Open FOCAL.csv with Excel. If there is a problem (meaning that all the data appears in the first column), select the first one, use the button convert (in the menu called « data ») and choose the comma for separating.

   b. Keep the columns *time, name, behaviour, name, near, distance, behaviour, comments* of the file CSV in excel (save in xls format with the name *nameofthefollow*(site_date(yymmdd))_*nameofanimal_FOCAL*(if there is more than one animal). For example : CC080819_A_FOCAL.xls.

   c. Add (on the right) the names of the columns of the file « entete.xls » in the new file (created in step b)

   d. Transcribe the co-occurrence data related to one observation to only one line. In the original file FOCAl.csv, if there is several vessels in interaction with the focal animal, the number of lines corresponds to the number of interactions, and at this point all these lines will be converted in one. So we needed to organize the number of interactions by the kind of objects (zodiac, big boat, kayak, other kind of vessels, other marine mammals) and by class of distance (100, >100 & <200, >200 & <300, >300 & <400, >400 & <1000). The average of distances is needed only for the vessels. After doing that correctly, delete the lines with the used information.

e. Verification

f. Keep this (these) file(s) in the folder of the focal follow

2) Change the observation database.CSV (with Excel)

a. Save the .CSV in the excel's format of **2007(.xlsx)**. The name must be *nameofthe follow(site_date(yymmdd))_final.* For example : CC080819_final.xlsx.

b. We must keep the following fields in **THIS ORDER** and written like this and without space (use _): **Date** (yyyy-mm-dd), **Time** (hh:mm:ss), **Date_time** (we mus add, leave it empty for now), **Name**, **Agent** (we must add and fill with the information of the column comments*) **Behaviour**, **Composition**, **Sec_Behv**, Bearing (replace bearing by **Hor_Angle**), **Distance, Vert_Angle**, **East**, **North**, **Comments**, **Site** (we must add and fill)**.

***Agent :**

Agent_id	**Agent_name**
ba	Minke whale
bp	Fin whale
bm	Blue whale
mn	Humpback whale
dl	Beluga

pm	Sperm Whale
pp	Harbor Porpoise
S	Seal sp
la	Dolphin sp
Z	Zodiac
G	Big excursion boat
pl	personnal boat
C	cargo boat
K	Kayak
au	Other
uk	Unknown
F	Ferryboat

**** Site :**

Site_id	**Site_Name**
1	Bergeronnes
2	Mer et monde
3	Pointe-Noire
4	Escoumins

c. Sort out by the column Name (custom sort: on a first time by the letters of alphabet and on the second time by the numeric order) , and after, by time : chronologically.

d. Copy and paste the columns from “entete.xls”.

e. Sort out by the column Name (custom sort: on a first time by the letters of alphabet and on the second time by the numeric order) , and after, by time : chronologically.

f. Fill in Agent and Site columns.

3) Join the FOCAL to the Observation database(with Excel)

a. In Excel join columns of the file FOCAL (only the one wich where extract from file entete.xls) to the file DAT. Logically, when the two files are sort out by the chronological order, you just need to do a copy/past, but always control that the data about interactions are joined for the good observation (according to the time). Add the name of the columns too. If there is several FOCAL for one DAT, repeat the operation.

4) Adding movement parameter (with Excel)

a. Cut all the data without position (tips: sort by the East(or North) column) and paste them on a other excel sheet (not on a other file)

b. Sort out by the column Name (special sort: on a first time by the letters of alphabet and on the second time by the numeric order, and after, by time: chronologically).

c. Fill the columns :

- In the column **Name (the last column) :** copy the contents of the firs column Name.

  After each of the following step, copy the column and paste (special paste - only values)*

- In the column **inter** : at the second line, (AT2) write :

  =SI(BB3<>BB2;-999;(B3-B2)*86400)
  and drag the equation until the last marine mammal observation. (B is the column Time)

- In the column **steplength** : on the second line (AU2) write :

  =SI(BB3<>BB2;-999;RACINE((M3-M2)^2+(L3-L2)^2)) and drag the equation until the last marine mammal observation. (L is the collumn East and M is the column North). In meters.

- In the column **vitesse :** on the second line (AV2) write :

```
=SI(BB3<>BB2;-999;(AU2/1000)/(AT2/60/60))
```

and drag the equation until the last marine mammal observation. (AT is the column inter and AU is the column steplength). The speed is expressed in km/h.

- Then copy all, and paste (special paste - only values).

- In the column **bearing** : at the second line (AW2) write :

```
=SI(BB3<>BB2;-999;SI(ET(L3=L2;M3>M2);0;SI(ET(L3=L2;M3<M2);180;SI(ET(L3>L2;M3=M2);90;SI(ET(L3<L2;M3=M2);270;SI(ET(L3>L2;M3>M2);0+(DEGRES(ATAN((ABS(L3-L2))/(ABS(M3-M2)))));SI(ET(L3>L2;M3<M2);90+(DEGRES(ATAN((ABS(M3-M2))/(ABS(L3-L2)))));SI(ET(L3<L2;M3<M2);180+(DEGRES(ATAN((ABS(L3-L2))/(ABS(M3-M2)))));270+(DEGRES(ATAN((ABS(M3-M2))/(ABS(L3-L2))))))))))))
```

and drag the equation until the last marine mammal observation. (L is the column East and M is the column North)

- In the column **brgprev** : at the second line (AX2) write :

```
=SI(BB2<>BB1;-999;AW1)
```

and drag the equation until the last marine mammal observation. Copy all - paste (special paste - only values). (AW is the column bearing and AX is the column brgprev)

- In the column **turnangle** : on the second line (AY2) write :

=SI(OU(AW2=-999;AX2=-999);-999;SI((AW2-AX2)>180;(AW2-AX2-360);SI((AW2-AX2)<-180;(AW2-AX2+360);(AW2-AX2))))
and drag the equation until the last marine mammal observation. (AW is the column bearing and AX is the column brgprev)

- <u>In the column **dist_cumul**</u> : on the second line (AY2) write :

  =SI(BB2<>BB1;0;AU1+AZ1)
  and drag the equation until the last marine mammal observation. (AU is the column steplength and AZ is the column dist_cumul)

d. Add data without position at the end of the observations database.

e. Sort out by the column Name (special sort: on a first time by the letters of alphabet and on the second time by the numeric order, and after, by time : chronologically).

- Fill the column **Interval_respi**. Calculate the breathing interval (for animals only) by this way : on the second line of this column (BA2), write:

  =SI(BB3<>BB2;-999;(B3-B2)*86400)
  and drag the equation until the last marine mammal observation. (B is the column Time).
- Then copy all, special paste –only values.

- Delete the last column Name.

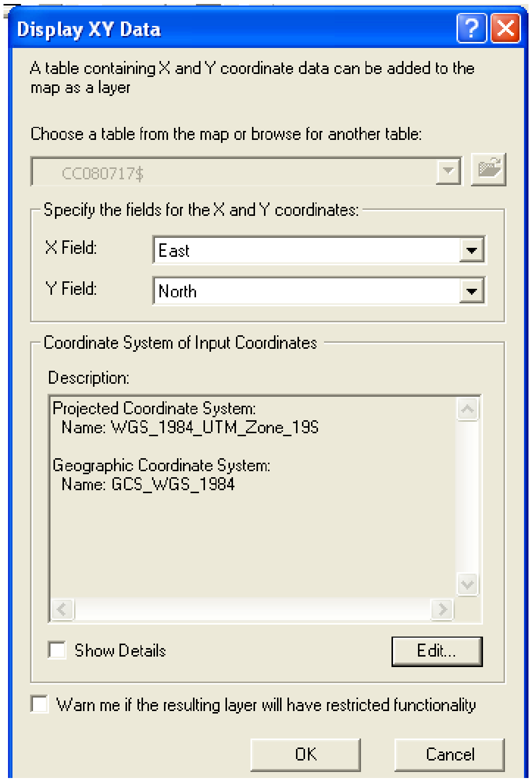
f. Insert a line before the first observation line. Copy the first line of the file first_line.xls and paste it in the first line of your database.

g. Save this file in the format **excel 1997-2003** with the same name in the folder of the follows. CCyymmdd_finalGIS.

5) Import the file <u>.xls</u> in the GIS

a. Open the DAT (xxx_final.xls) in ArcGIS

b. Right click on the file, *Display XY Data.* Choose the good field for the coordinate XY and the good projection (button edit/button select/Projected Coordinate Systems/Utm/Wgs 1984/WGS 1984 UTM Zone 19S.prj/button add/bouton apply). This projection is not for our project, but she is used for this data (in Cyclop), so **always** select this projection at this stage.



Display XY Data

A table containing X and Y coordinate data can be added to the map as a layer

Choose a table from the map or browse for another table:

CC080717$

Specify the fields for the X and Y coordinates:

X Field: East

Y Field: North

Coordinate System of Input Coordinates

Description:

Projected Coordinate System:
Name: WGS_1984_UTM_Zone_19S

Geographic Coordinate System:
Name: GCS_WGS_1984

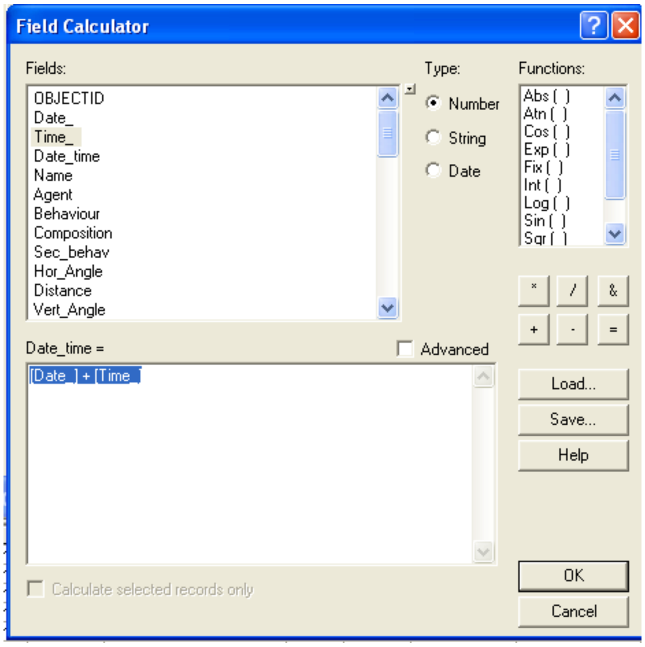
☐ Show Details

☐ Warn me if the resulting layer will have restricted functionality

c. Right click on the file Events/ data/ Export data. Choose the kind of file and Personal Geodatabase feature classes. Select the Personnal Geodatabase Observations_terrestres.mdb and the good Feature dataset (according to the main species followed) Name the feature class site_date(yymmdd), for example CC080819. By exporting an Events directly in a Feature dataset, this one take automaticaly the projection of it (wich is the good projection for our project).

d. Then, fill the field Date_time. Right click on the feature class/ Open attribute table/ right click on the field Date_time/ Field Calculator and write [Date_] + [Time_].

e. Do this step only if you did the step 4e. In the editor menu, choose Start editing and select the feature class. Then, right click on the feature class/ Open attribute table. Select the first line (be sure that is the line you added before). Then right click on this line and Delete Selected. In the editor menu, click on Save Edits and on Stop Editing.



Type: ● Number

Date_time =

[Date_] + [Time_]

f. Separate the feature class in different feature classes, **if more of one animal have been observed during at least 30minutes**. Like this:

- Sort out the feature class in chronological order (right click on the field date_time, sort ascending)

- Select manually in the table, the other animal who is observed, as well as the vessels and the secondary animals observed during period of observing. Try to cut after a break. **Don’t cut the follow in two parts.**

- Export (right click on the feature class, data, export data), specify the exportation of data selected only and select the Personnal Geodatabase Observations_terrestres.mdb and the good Feature dataset (according to the main species observing). Name the feature class site_date(yymmdd_2), for example CC080819_2. If it is necessary, remplace the _2 par _3 ou _4 ou _5…
- Then, delete the data selected in the original feature class. (Start Editing, delete selected, Save Eedits, Stop Editing).

Annexe 4. Land-based station positioning error

It is known that the measurements taken with a theodolite or total station have an associated error. Würsig *et al.* (1991) provided theoretical errors which depended on the observation site height, precision of the height measurement and as a function of the target distance (Figure 86). However, the best way to known the error associated with a study is to conduct a calibration. For the present study, a calibration was performed from the land-based station located at les Bergeronnes.

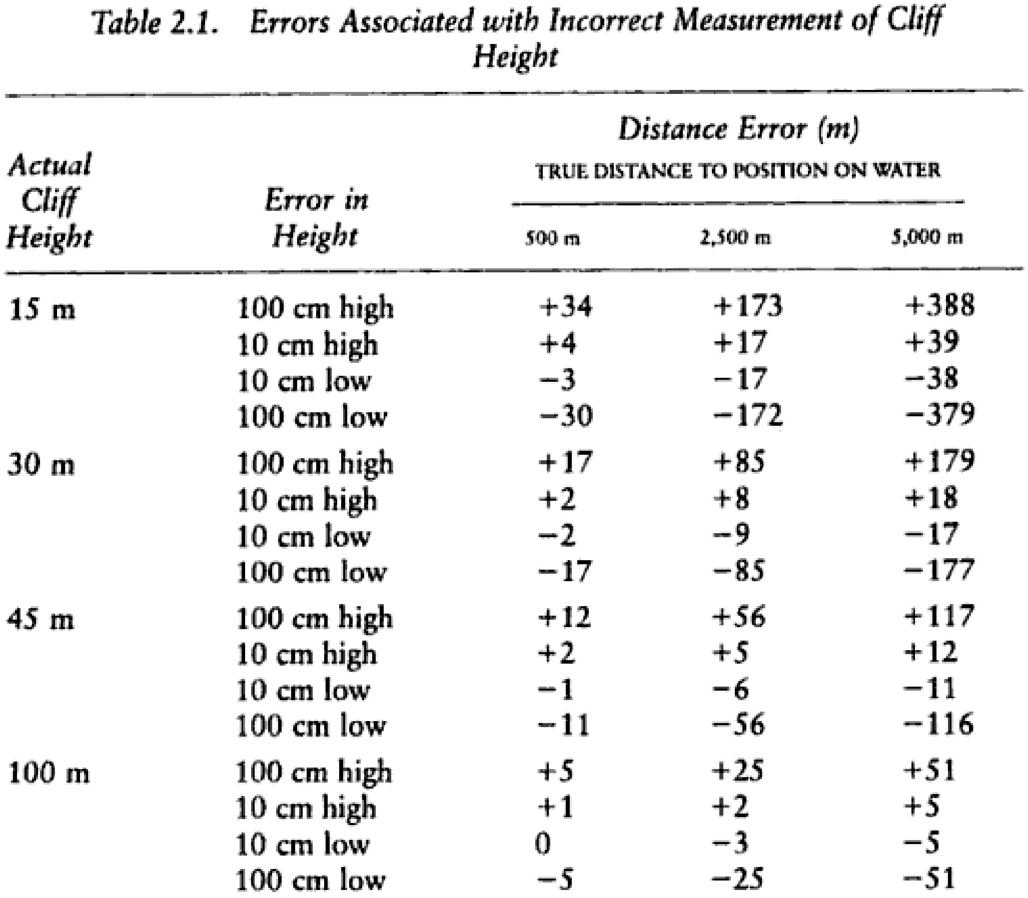


***Table 2.1.** Errors Associated with Incorrect Measurement of Cliff Height*

Actual Cliff Height	*Error in Height*	*Distance Error (m)* TRUE DISTANCE TO POSITION ON WATER 500 m	2,500 m	5,000 m
15 m	100 cm high	+34	+173	+388
	10 cm high	+4	+17	+39
	10 cm low	−3	−17	−38
	100 cm low	−30	−172	−379
30 m	100 cm high	+17	+85	+179
	10 cm high	+2	+8	+18
	10 cm low	−2	−9	−17
	100 cm low	−17	−85	−177
45 m	100 cm high	+12	+56	+117
	10 cm high	+2	+5	+12
	10 cm low	−1	−6	−11
	100 cm low	−11	−56	−116
100 m	100 cm high	+5	+25	+51
	10 cm high	+1	+2	+5
	10 cm low	0	−3	−5
	100 cm low	−5	−25	−51

Figure 86. Errors associated with the measurements taken with a theodolite or total station (Source: Würsig *et al.* (1991).

The calibration was performed the 20th August 2012. The target boat was the SSLMP zodiac Astram, and the error between the positions taken with the total station and the GPS was calculated (Figure 87). Once entered in Cyclops the height of the station was set to 18.302 instead of 16.102, and at the tide file the first value was set to zero instead of 2.2. The declination of 2012 was used (-17.47).

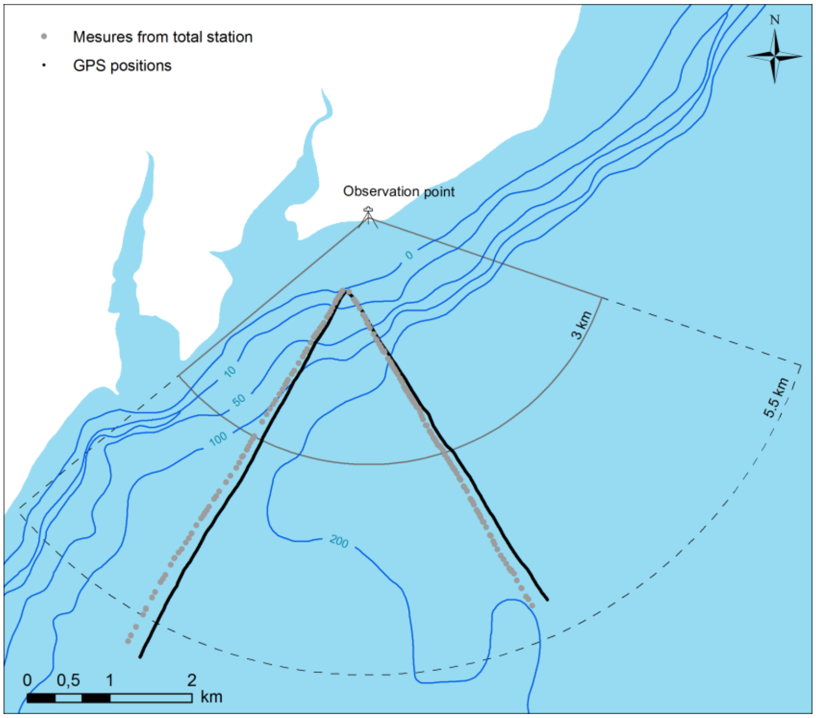


Figure 87. Overlay of the measurements taken with the total station from the land-based station at Les Bergeronnes and of the coordinates of the zodiac Astram recorded each second with a hand held GPS.

As illustrated at the Figure 88, each position taken with the total station at 1km from it, is displaced of around 50 m in relation to the GPS. Targets at 6 km from the total station would be 250 m displaced in relation to the GPS. This difference of position in relation to the GPS is not of concern to the analysis conducted in the scope of the present work. However, this may concern if data collected from the land-based stations would be used to habitat use modelling, for example.

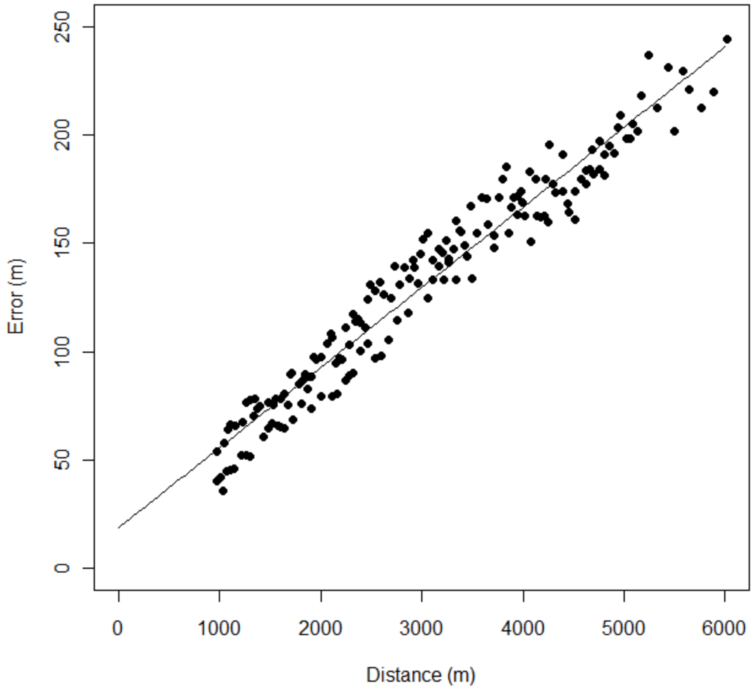


Figure 88. Error of the measurements taken with the total station in relation to the coordinates of the zodiac Astram recorded each second with a hand held GPS.