# ECOSYSTEM RESEARCH INITIATIVE ADVISORY REPORT: FORAGE SPECIES RESPONSIBLE FOR THE PRESENCE OF BLUE WHALES (*BALAENOPTERA MUSCULUS*) IN THE ST. LAWRENCE ESTUARY

*Photo: A blue whale during feeding (Véronique Lesage).*

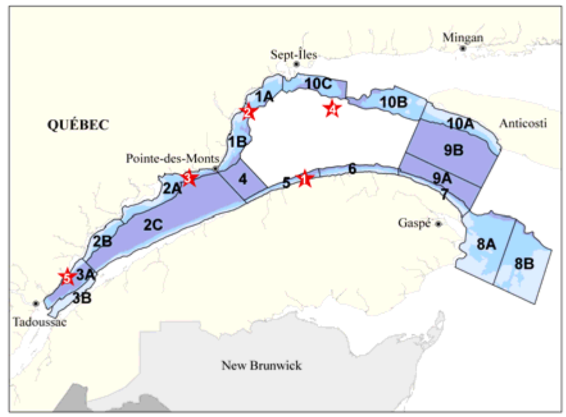


*Figure 1: Map of the Estuary and the north-western Gulf of St. Lawrence.*

## Context:

*The 2005 Strategic Plan "Our Waters, Our Future" presented an updated vision for the Department of Fisheries and Oceans Canada (DFO) and a direction for its objectives and priorities over the next five years. The Plan's vision was to offer high-quality services to the Canadian population with a view of ensuring the sustainable development and safe use of Canadian waters. The Strategic Plan was also used to identify research priorities. One proposal was to conduct pilot projects focusing on regional issues, in the form of Ecosystem Research Initiatives (ERIs). Over the course of two workshops, held in June and July 2007 at the Maurice Lamontagne Institute (MLI), DFO scientists from the Quebec Region met to discuss ways to define the ecosystem approach and how to apply it in the context of regional ERIs. In September 2007, a third workshop was held to identify major research topics, making sure to include a maximum number of issues identified by internal and external clients. This advisory report focuses on the work conducted on the following topic:*

- *Forage species responsible for the presence of blue whales in the St. Lawrence Estuary*

*This science advisory report is a result of the peer-reviewed workshops that took place from March 28 to 31, 2011, and February 14 to 16, 2012.*

*Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at: [www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm](www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm).*

## SUMMARY

This document provides information on: (1) the effect of natural processes and factors on the abundance and distribution of forage species (euphausiids, or krill) that are likely to impact the distribution of blue whales, and (2) the impact of human activity on the dynamic of some of the ecosystem's key species and the consequences of this on the whales' use of resources.

Issue: Forage species – Krill distribution

- In 2009, krill biomasses were estimated for the Estuary, the north-western Gulf, and off the coast of Gaspé based on acoustic surveys with high spatial resolution. The results suggest that *Thysanoessa raschii*, and not *Meganyctiphanes norvegica*, is the dominant species (by biomass). In June 2008, a survey of the Pentecôte region with more limited spatial resolution estimated the largest one-time level of krill ever observed in the Gulf.

- In 2009, the spatial distribution of *T. raschii* showed significant differences between June and August, although total biomass remained similar. In June, there were several accumulations located along the northern and southern coasts of the Estuary and at the head of the Laurentian Channel. There was also a large aggregation extending from Mont-Louis to Petite Vallée, and another off the coast of Gaspé. In August, there were fewer high-accumulation areas, but density was higher.

- In June and August 2009, the highest densities of *T. raschii* were often located above the slope (100–180 m) of the Laurentian Channel. However, a higher density of *T. raschii* was located above the deep-water channel at Les Escoumins, and the highest densities along the southern shore of the Estuary were concentrated above the shelf. The seasonal distributions of *M. norvegica* were more uniform between bathymetric areas. *T. raschii* was consistently located higher in the water column (20 m on average) than *M. norvegica*.

Issue: Forage species – Estuary supply and connectivity between regions

- The primary exchange between the Gulf and the Estuary by hydrodynamic circulation occurs off the coast of Pointe-des-Monts, where the current can be directed westward (entering into the Estuary) or southward (bypassing the Estuary), depending on the mode of regional circulation—hence the concept of a “valve”. Depending on the direction of the current, the krill is directed either toward the Estuary (open valve) or south to the Gaspé Peninsula (closed valve), where it can be re-circulated into the Anticosti Gyre or carried downstream toward Gaspé and the southern Gulf.

- The average relative densities of krill were higher at the oceanographic mooring stations in the Estuary than those in the north-western Gulf, when averaged over the year. However, monthly densities varied significantly, which is consistent with the movement of the aggregations. Some of these aggregations appeared to extend over several dozen kilometres. The cumulative transport of the krill biomass indicates net transport in an upstream direction at all stations, except the Gaspé Current station, where it is downstream. The results show the persistence of nycthemeral vertical migration throughout the year, even under the ice in winter, and illustrate how it is controlled by photoperiod.

- The circulation patterns corresponding with the open and closed valve conditions were found both in current-meter readings (mooring stations) and in the results of a numerical circulation

simulation. The analysis revealed two distinct advection modes for the krill in the Estuary: a seasonal mode, and short-time major events (i.e. storms).

- Irrespective of the open/closed valve concept, the transport of krill upstream in deeper waters (80–180 m) is more prevalent in winter and spring and does not necessarily occur along the north shore of the Estuary. At the surface (0–40 m), upstream krill transport along the north shore (open valve) occurs primarily in summer and fall. The passage of low-pressure systems can generate significant inflow from the north-western Gulf toward the Estuary, adding another level of variability to the seasonal pattern.

- A species' potential for transport depends on its daily migration pattern, diurnal depth, and influencing factors (e.g. seasonal and inter-annual variations in the light attenuation coefficient). The probability of transport is therefore potentially higher for *T. raschii* than *M. norvegica,* as the latter is found at a lower depth. However, it is difficult to predict how the estuarine circulation will be affected by future changes in the river flow of the St. Lawrence.

### Issue: Forage species – Blue whale habitats in the St. Lawrence Gulf and Estuary

- A new analysis of the marine mammal photo-identification data from the Mingan Island Cetacean Study (MICS) research station revealed that between 1987 and 2007, 333 blue whales were individually photo-identified in the Estuary and Gulf. Of this number, between 23 and 96 different blue whales (average ± SD = 60 ± 21) were recorded annually in the Estuary and Gulf. No time trends were observed.

- Baleen whales (blue, fin and Minke) in the north-western Gulf have been more strongly associated with concentrations of *T. raschii* than *M. norvegica*, making *T. raschii* the preferred prey for large whales. Blue whales were associated with aggregations where *T. raschii* were distributed in the first 100 m of the water column (surveys conducted during the day).

- In a study of the diving behaviour of blue whales in the Estuary, repeated observations of feeding at least 30 m from the surface, even in the daytime, confirmed a preference for shallow dives when food is available. This supports the idea that, to a certain extent, the quality of a habitat is not defined only by the density and abundance of prey, but also by its accessibility.

- The quantity of krill does not appear to be a limiting factor in the Estuary, even though the blue whale's competition for this resource ranges from secondary producers (other microzooplankton) to top predators (fish, baleen whales).

### Issue: Impact of marine traffic noise

- Marine traffic in the St. Lawrence Seaway (approximately 20 ships per day) produces sound levels that are above the Wenz reference level for high traffic, for at least 75% of the time within the first 200 metres of the water column. The noise levels were relatively stable throughout the 12-month ERI study, with slightly lower levels in winter (late January to early February) due to reduced traffic. Blue whales produce low-frequency sounds (below 200 Hz). Anthropogenic noise, such as marine traffic, can interfere with the detection of these sounds, and as a result, with a number of the whales' vital activities.

Issue: Pollutants

- Over the course of the period between 1994 and 2009, concentrations of persistent organic pollutants (POP) in *M. norvegica* were either decreasing (e.g. DDT and PBDE) or showed no significant trends (e.g. PCB and HCB). Contamination of *M. norvegica* by POPs appears to be a good indicator of recent changes in the environmental quality of the Estuary.

Issue: Indicators

- The ERI helped to determine potential physical, chemical and biological indicators of the ecosystem's status. A large number of these indicators are influenced by the Estuary's circulation. It is currently difficult to predict how this will be affected by future changes in the flow of the St. Lawrence river.

## BACKGROUND

For the past several years, the concept of an ecosystem-based approach has gained global popularity as a possible solution to the management problems related to the deterioration of marine ecosystems and their resources resulting from human activity (fishing, industrial development, aquaculture, etc.). In 2007, the Department of Fisheries and Oceans launched a number of regional scientific initiatives to test the application of such ecosystem-based approaches. The St. Lawrence Estuary was the site of one such Ecosystem Research Initiative (ERI). In consultation workshops involving scientists, internal and external clients, and managers, two main themes were decided upon for the implementation of this ERI: (1) a definition and characterization of the summer habitat of beluga whales (*Delphinapterus leucas*) in the St. Lawrence, and (2) forage species responsible for the presence of the blue whale (*Balaenoptera musculus*) in the lower St. Lawrence Estuary.

The purpose of the reference framework for the theme "Forage species responsible for the presence of the blue whale in the Estuary" was to provide information on four points: (1) a description of the pelagic habitats frequented by the blue whale, i.e. the characterization of pelagic communities in the Estuary in terms of structure, abundance, and spatial and temporal distribution; (2) an identification of the key environmental factors and processes that determine the abundance, distribution, quality, and behaviour of forage species (krill in particular) that are likely to play an important role in the seasonal dynamic of blue whale distribution; (3) an impact assessment of human activity on the dynamic of certain key species in the ecosystem and the consequences on the use of resources by blue whales in the Estuary; and (4) a development of indicators and protocols for the purpose of periodically assessing the state of the habitats. The main results for points 2 through 4 will be the focus of this report. This document may be useful for the development of the action plan or implementation plan for the Recovery Strategy for the Blue Whale, Northwest Atlantic Population, in Canada (Beauchamp et al., 2009).

In 2007, the St. Lawrence Estuary was identified by DFO as one of the Ecologically and Biologically Significant Areas (EBSAs) in the St. Lawrence marine ecosystem due to the particularity and complexity of the physical phenomena that produce hydrographic conditions conducive to the local production and accumulation of zooplankton and pelagic fish (DFO, 2007). The St. Lawrence Estuary is also an area of significance for marine mammals. A portion of the beluga (*Delphinapterus leucas*) and harbour seal (*Phoca vitulina*) populations in the Gulf reside there year-round (Michaud et al., 1990; Lesage et al., 2004), whereas at least ten other species (three pinnipeds and seven cetaceans) visit the Estuary seasonally, generally when the water is free of ice. The presence of blue whales and other whales in the St. Lawrence during the summer is, unquestionably, related to feeding. However, what remains unclear is the proportion of the blue whale population in the northwest Atlantic that frequents the Estuary and the Gulf, as well as the manner in which each individual partitions its food search efforts between the available summer feeding areas.

Among the threats described in the Recovery Strategy for the Blue Whale (Beauchamp et al., 2009), two of these threats present a potentially high risk for the population, either due to the likelihood of their occurring and/or the seriousness of their theoretical impact: the availability of food for the blue whale, and anthropogenic noise, resulting in a deterioration of the underwater acoustic environment and a change in the blue whale's behaviour. The blue whale is oligophagous, meaning it eats essentially only one food source, in their case euphausiids (krill), although copepods may also account for part of their diet (Sears and Calambokidis, 2002). Because they have high energy needs, it is believed that these animals are restricted to locations where the seasonal aggregations of prey are not only recurring, but are also high in density (Acevedo-Gutiérrez et al., 2002). Such areas, associated with upwelling, have been identified in the St. Lawrence (Rose and Leggett, 1988; Koutitonsky and Bugden, 1991). In particular, the head of the Laurentian Channel has been shown to be an area with a high concentration and recurring retention of krill. Other such locations include the Jacques-Cartier Strait, the area around Anticosti Island, the length of the North Shore in the north-western Gulf, and Gaspé (Sourisseau et al., 2006). There is a close juxtaposition between these aggregation areas and regions preferred by cetaceans (Lesage et al., 2007). The lack of diversity in the blue whale's diet, as well as their possible dependency on sites with high prey density, makes them particularly vulnerable to changes in the abundance and/or distribution of their prey.

All the information collected as part of the ERI was presented and discussed at annual regional workshops, to which members of the regional scientific community and all managers concerned by or possibly interested in the deliverables of the ERI (managers of DFO departments, Species at Risk, Health of the Oceans, Saguenay–St. Lawrence Marine Park) were invited. All the information was submitted for peer review at a synthesis and integration workshop in winter 2011. The full results for this ERI theme, as well as details on the information collected for this report, will be published in a research document by the Canadian Science Advisory Secretariat.

# ANALYSIS

## Issue: Forage species – Krill distribution

Acoustic surveys with high spatial resolution were conducted on a regional scale (the Estuary and the north-western Gulf) in 2008 and 2009. The sampling work was concentrated at the shelf and slope levels, where the zooplankton biomass tends to be higher, while also sampling deeper areas with lower densities. In all the surveys, the biomass of euphausiids (or krill) was estimated for *Thysanoessa* spp. (primarily *T. raschii* and to a lesser extent *T. inermis*) and *Meganyctiphanes norvegica*.

In 2009, the total biomass of *T. raschii* for all strata (full coverage of the region) was 348 ± 59 kt in June and 543 ± 53 kt in August. The *M. norvegica* biomass was estimated at 289 ± 35 kt in June and 344 ± 25 kt in August. Total krill biomass in the survey region was therefore estimated at 637 kt in June and 887 kt in August 2009. The highest one-time value, however, was recorded in

June 2008 in the Pentecôte region (131 kt, or 66 ± 18 kt for *T. raschii* and 64 ± 13 kt for *M. norvegica* over an area of 1,286 km$^2$) (Figure 2). This value is the largest systematic estimate of krill abundance and density documented in the Gulf to date.

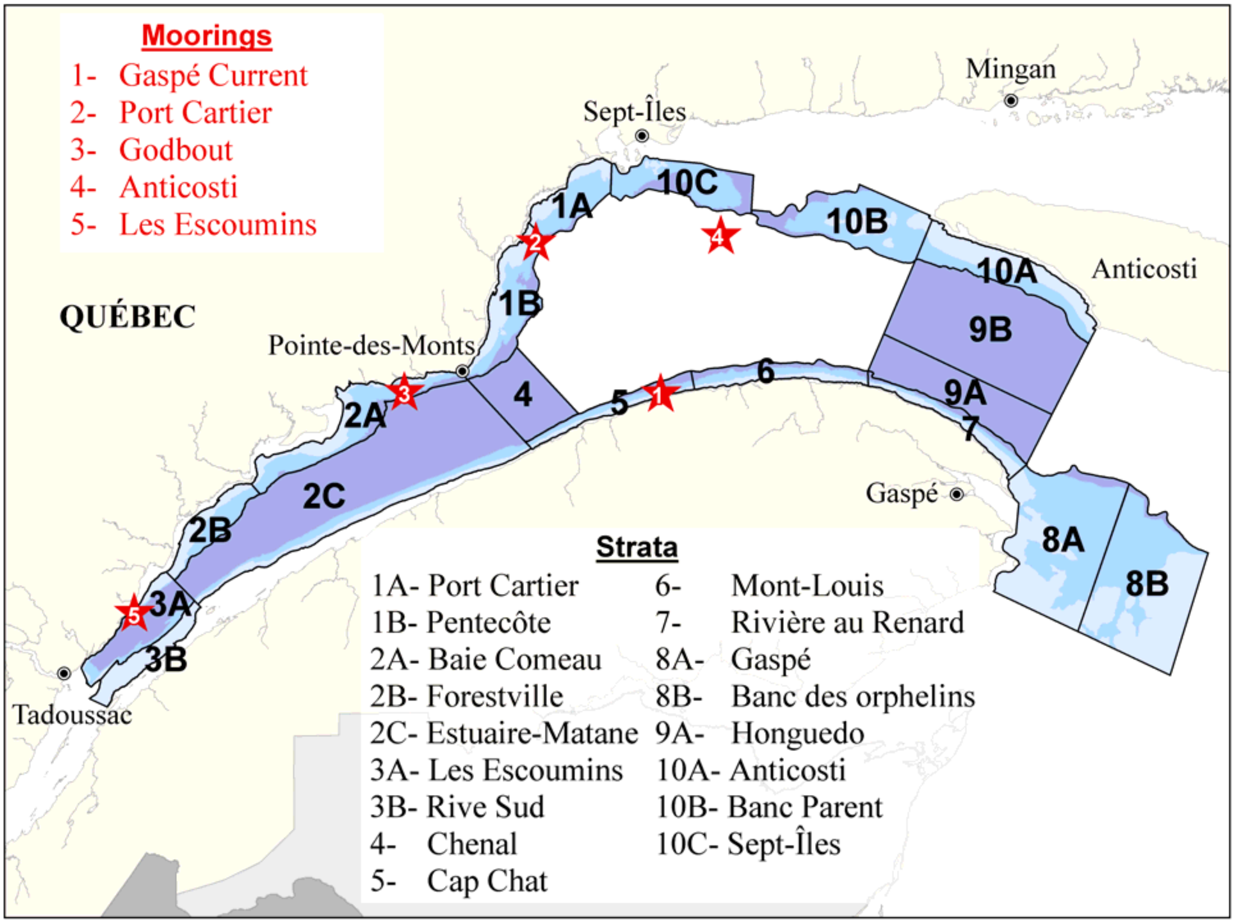


*Figure 2: Map showing the strata sampled for regional acoustic surveys of zooplankton and the stations (red stars) for annual serial measurements of currents, water mass characteristics, and acoustic biomass. Habitats defined based on depth are also shown (from the coast to the open water: shelf, slope and channel).*

The spatial distribution of *T. raschii* showed significant differences between June and August 2009, although the total biomass sampled was similar for both months. In June, the accumulations were located along the northern coast of the Estuary, from Baie-Comeau to Forestville, at the head of the Laurentian Channel, and along the southern coast of the Estuary. There was also a large aggregation extending from Mont-Louis to Petite Vallée, and an accumulation was also present off the coast of Gaspé. In August, there were fewer high-accumulation areas, but density was higher. The aggregations were primarily located along Pentecôte, off Forestville, between Matane and Cap-Chat, and off the coast of Gaspé, where densities between 2.6 and 4.3 times higher than those in June were recorded. However, densities were 3.3 to 11 times lower along the northern coast of the Estuary, at the head of the Laurentian Channel, and in the Gaspé Current. Another characteristic of the June and August 2009 surveys was the absence of *T. raschii* between

Anticosti Island and Sept-Îles. From June to August, densities of *M. norvegica* were 2.4 to 3.6 times lower, except for Gaspé, where the density increased by a factor of 5.3.

The survey area was subdivided into bathymetric areas: the shelf (10–100 m), the slope (100–180 m) and the channel (>180 m) in order to study the vertical distribution of the species (Figure 2). In June 2009, the highest densities of *T. raschii* were found above the slopes of the Laurentian Channel and not above the shelves near the coast or above the deep-water channel. *T. raschii* densities were even more concentrated in August above the slopes. However, this general pattern was not seen in all sectors. In June and August 2009, a higher density of *T. raschii* was located above the channel at Les Escoumins, whereas the highest densities were concentrated above the shelf along the southern shore of the Estuary. The seasonal distributions of *M. norvegica* were more uniform between bathymetric areas.

The depth at which the maximum biomass of each species of krill was located was greater outside the Estuary than inside it. Although there was overlapping of vertical distributions, *T. raschii* was consistently located higher in the water column (20 m on average) than *M. norvegica*.

In summary, the results of the seven regional acoustic surveys conducted between 2008 and 2009 showed regions with significant krill accumulation in the north-western Gulf, particularly north-east of Pointe-des-Monts, in the Gaspé Current and off the coast of Gaspé, at levels often higher than those observed in the Estuary. The results also suggest that in 2008 and 2009, *T. raschii* was the dominant krill species (in biomass) and not *M. norvegica*. These surveys also show that the distribution of *M. norvegica* extends further away from the shore and more uniformly at greater depth, between the slope and the channel, whereas *T. raschii* is primarily located above the slope and shelf.

## Issue: Forage species – Estuary supply and connectivity between regions

The primary exchange between the Gulf and the Estuary by hydrodynamic circulation occurs off the coast of Pointe-des-Monts, where the current can be directed westward (entering into the Estuary) or southward (bypassing the Estuary), depending on the mode of regional circulation—hence the concept of a "valve." Depending on the direction of the current, the krill is directed either toward the Estuary (open valve) or south to the Gaspé Peninsula (closed valve), where it can be either re-circulated into the Anticosti Gyre or carried downstream toward Gaspé and the southern Gulf. The Estuary's krill supply mechanism was studied by combining field work and results from hydrodynamic 3D modelling coupled with a particle transport model. The work was carried out at five sites located inside the circulation pattern (Figure 2). The instruments moored at the stations included Acoustic Doppler Current Profilers (ADCPs), which provided information on the speed and direction of the currents as well as the zooplankton biomass (dominated by krill) between 2007 and 2009.

In general, and for the two years of observations, the estimated average relative krill densities were higher year-round at the Estuary stations than those along the circulation route. However, monthly densities varied significantly, which is consistent with the movement of the aggregations. Some of these krill aggregations appeared to extend over several dozen kilometres. The cumulative transport of the krill biomass indicates net transport in an upstream direction at all stations, except the Gaspé Current station, where the transport is downstream. The results show the persistence of nycthemeral vertical migration throughout the year, even under the ice in winter, and how it is controlled by photoperiod.

The circulation patterns corresponding with the open and closed valve conditions were found both in the ADCP readings and in the modelling results. The analysis revealed two distinct advection modes for the krill in the Estuary: a seasonal mode, and short-time major events. The transport of krill upstream in deeper waters (80–180 m) is more prevalent in winter and spring and does not necessarily occur along the north shore. At the surface (0–40 m), transport is mostly upstream along the north shore (open valve), in summer (from July) and fall. During this period, outflow of fresh water occurs along the south shore of the Estuary. During spring, the surface current (freshwater outflow) becomes a coastal jet turning northwards in the upstream half of the lower Estuary to flow along the north shore until it branches off toward the south near Pointe-des-Monts. This circulation pattern seems to prevent the inflow of coastal waters from the north-western Gulf into the Estuary. In addition to this variability, or seasonal pattern, is the influence of short-time events, such as the passage of low-pressure systems, which, depending on their trajectories, may generate significant inflow from the northwest of the Gulf toward the Estuary (open valve). Maximum advection occurs at the surface and can reach depths of 100 to 150 m. Storms that generate inflow along the north shore are those with an isobar configuration that is conducive to water pile-up due to wind along the north shore in the Sept-Îles–Pointe des-Monts section. Moreover, when the low-pressure centre moves along the axis of the Estuary, the water level adjusts to the air pressure (inverse barometer effect), which helps generate upstream currents, although they are lower in intensity.

Since the valve mechanism primarily involves upstream currents at the surface and in the cold intermediate layer (CIL), the probability of transport is potentially higher for *T. raschii* than *M. norvegica* which is located at a lower depth. A species' potential for transport depends on its daily migration pattern, diurnal depth, and influencing factors (e.g. seasonal and inter-annual variations in the light attenuation coefficient). The impact of the diurnal depth differences between *T. raschii* and *M. norvegica* on their upstream transport potential was simulated using a numerical model. Upstream transport of krill through the Pointe-des-Monts section was observed primarily over three periods when the valve was open, according to field measurements (ADCP) and modelling. Additionally, the simulated currents at the depth of the centre of the *T. raschii* mass were generally stronger than those associated with the centre of the *M. norvegica* mass, particularly in the summer on the north side of the Laurentian Channel, in the north-western Gulf and the Estuary. The simulated *T. raschii* upstream flows through Pointe-des-Monts were the result of transport events both in the CIL (during the day) and at the surface (at night), which illustrates the strong consistency in the direction of currents between the surface and the CIL in this section from August to October.

## Issue: Long-term stability of the hydrodynamic system

The transport of krill into the Estuary (open valve) and the location of krill accumulations in the survey sector are strongly related to the hydrodynamic circulation. This section will outline potential changes to the hydrodynamic system in relation to climate change. River flow, stratification, and estuarine circulation are closely related. In a numerical simulation of the St. Lawrence system (J. Chassé and D. Brickman, GFC-BIO, DFO, personal communication; Galbraith et al., 2011), estuarine amplification, defined as the ratio between the transport of salt water exiting the Estuary and the net transport of fresh water exiting the Estuary, varied by at least six in June, up to a maximum of 23 in December (i.e. the transport of water exiting the Estuary is as much as 23 times greater than the river flow in December). However, it should be noted that these transports also include lateral currents that are not associated with the estuarine circulation, such as incursions of the Anticosti Gyre in the mouth of the Estuary. In these simulations, when flows and transports were averaged over the year, an increase in river flow resulted in estuarine transport (salt water entering at the bottom and exiting in the surface layer) that was relatively stable, as it was compensated by lower estuarine amplification. However, on a month-by-month basis, an increase in spring freshets resulted not only in decreased estuarine amplification, but also in decreased estuarine transport, as the Estuary becomes so stratified that the river freshwater does not mix as much with the underlying water but instead glides over it, thereby reducing the transport of water exiting the Estuary and, consequently, the inflow from the Gulf. In the future, the distribution over time (i.e. the annual cycle) of a more or less important freshwater outflow would therefore be just as significant as an increase or a decrease. However, simulations by Saucier et al. (2009) of future reduced flows show that estuarine circulation would be reduced in the summer and increased in the winter. As a result, it is difficult to predict how estuarine circulation will be affected by future changes in the river flow of the St. Lawrence.

## Issue: Forage species – Blue whale habitats in the Estuary and Gulf of St. Lawrence

A new analysis of the marine mammal photo-identification data from the Mingan Island Cetacean Study (MICS) research station was conducted as part of the ERI (Comtois et al., 2010). Between 1987 and 2007, 333 blue whales were individually photo-identified in the Estuary and Gulf. Of these, 94 individuals were identified in the Jacques-Cartier Strait region (Minganie). In comparison, and despite a reduced sampling effort, many more blue whales were individually identified in the Estuary (220 individuals), the Gaspé Peninsula (134) and between Sept-Îles and Pointe-des-Monts (114). Based on these data, between 23 and 96 different blue whales (average ± SD = 60 ± 21) were recorded annually in the Estuary and Gulf. No time trends were observed, possibly due to the spatial and temporal variability of the sampling coverage. Currently, the size of the blue whale population in the Northwest Atlantic is not known, but experts estimate that it is unlikely that there are more than 250 mature individuals (Sears and Calambokidis, 2002). The actual proportion of the population that frequents the Estuary and Gulf of St. Lawrence remains unknown.

The results from Comtois et al. (2010) also showed that 67% of the 333 blue whales that were photographed were seen during at least two different years in the St. Lawrence. Of the individuals seen in more than one year, three-quarters were observed in more than one region. This information shows the significance of the Estuary and the Gulf for the whales and their nomadic tendencies.

Based on the photo-identification data, blue whales are generally observed in the Estuary between June and October, with increased sightings in August and September. However, a few observations were also reported in May and December. Additional indications of blue whales frequenting the Estuary were obtained for the ERI through the deployment of autonomous hydrophones to record the whales' vocal activity. Preliminary results suggest that individuals remain in the region until late fall and early winter.

Regional surveys carried out during the day, when the krill are at a lower depth, showed that the whales in the north-western Gulf are more strongly associated with *T. raschii* than *M. norvegica* concentrations. Between 2008 and 2009, *T. raschii* had a higher total biomass with denser local aggregations and they remained at a more shallow depth in the water column during the day than *M. norvegica*. The species could therefore be a choice prey for large whales.

Although it is expected that blue whales would favour the highest density aggregations to satisfy their energy requirements, they were rarely observed directly at the dense core of *T. raschii* aggregations in the August 2009 study. Moreover, there were several high-density aggregation areas without blue whales, whereas other areas with lower densities were highly frequented. Rather, the blue whales were associated with aggregations where *T. raschii* were distributed in the first 100 m of the water column.

We noted during the acoustic surveys that *T. raschii* was consistently located higher in the water column than *M. norvegica* (20 m on average). The presence of krill at depths of less than 100 m may also be influenced by the species' life cycle. Surface aggregations observed during the day in 2009 contained a high proportion of mature individuals (ready to spawn). Since spawning is often associated with phytoplankton blooms, blue whales could benefit from these areas of overlapping krill aggregations and phytoplankton blooms. In addition to the spatial aspect, the notion of the blue whale's habitat may therefore also have to take into account a temporal aspect, associated with the krill's life cycle and behaviour.

A study conducted in the Estuary (not part of the ERI) showed that shallow dives required less recovery time on the surface and allowed the whales to achieve higher hourly feeding rates. Repeated observation of feeding at least 30 m from the surface, even in the daytime, confirmed a preference for shallow depths when food is available, and supports the idea that, to a certain extent, habitat quality is not defined only by the density and abundance of prey, but also by its accessibility.

## Issue: Potential causes of mortality in the Estuary

The impact of disruptions caused by human activity is difficult to determine, particularly due to the lack of information on the dynamic of marine mammal populations and to the diversity of human activities and their consequences in the Estuary and Gulf of St. Lawrence. Apart from traditional hunting and death from natural causes (i.e. entrapment under ice and predation by killer whales), a total of nine threats to the recovery of the in the Northwest Atlantic blue whale population were identified as part of the recovery program (Beauchamp et al., 2009). Given the small size of the population, even activities affecting a small number of individuals could have a significant impact on the survival of the species in the Atlantic. Among the threats described, two present a potentially high risk for the blue whale population, either due to the likelihood of their occurring and/or the seriousness of their theoretical impact: the availability of food for the blue whale and anthropogenic noise, resulting in a deterioration of the underwater acoustic environment and a change in the blue whale's behaviour. Medium-high risk threats include persistent marine pollutants, collisions with ships, and disturbances caused by whale watching for touristic or scientific purposes. Lower-risk threats include physical damage caused by noise, accidental capture in fishing gear, epizootic diseases (epidemics that affect the animals), toxic algal bloom and toxic product spills. Identifying the causes of mortality of marine mammals from beaching data is therefore important as a biological indicator and as a management tool for evaluating the effectiveness of established conservation measures both inside and outside protected marine areas. For the blue whale and other large whales, the situation is complicated by the fact that they sink rapidly after dying from collisions with ships.

## Issue: Influence of predation on the availability of krill

Potential predation of *T. raschii* and *M. norvegica* was estimated based on feeding data for the main species in the Estuary (Ouellet et al., 2012). Main predators of krill (and therefore competitors for the blue whale) include invertebrates (Northern shrimp *Pandalus borealis*, hyperiid amphipod *Themistho libellula* and gelatinous plankton), fish (capelin, small demersals, etc.) and marine mammals (minke whale *Balaenoptera acutorostrata*). The proportion of krill in the diet of the different species studied is 12.1% on average. For the blue whale, this proportion is around 95%, and for small pelagic fish, between 20% and 58%. Total predation potential is around 15.0 t $km^{-2}$ $year^{-1}$ for *M. norvegica* and 19.5 t $km^{-2}$ $year^{-1}$ for *T. raschii* (i.e. approximately 98 kt and 127.5 kt respectively per year) in the Estuary. The quantity of krill does not appear to be a limiting factor in the Estuary (35% of production is used on average for predation), even though the blue whale's competition for this resource ranges from secondary producers (other microzooplankton) to top predators (fish, whales).

## Issue: Impact of marine traffic noise

Marine mammals use various sounds to communicate with one another, to detect and locate their prey, to perceive various properties in their environment by analyzing the "soundscape," to detect the presence of predators and other threats and to navigate underwater. Blue whales produce low-frequency sounds (< 200 Hz). Anthropogenic noise, such as marine traffic, can interfere with the detection of these sounds, and as a result, with a number of the whales' vital activities. Thanks to the ERI, an annual series of complete recordings was carried out using passive acoustic monitoring (PAM), or fixed hydrophones, in the middle of the waterway.

The 12-month noise series recorded during the ERI shows a median level of 112 dB re 1 µPa for the 10–900 Hz band, which is comparable to previous measurements taken at the station at the mouth of the Estuary. The noise levels were relatively stable throughout the 12-month series, with slightly lower levels in winter (late January to early February) due to reduced traffic.

Marine traffic in the St. Lawrence Seaway (approximately 20 ships per day) produces sound levels that are above the Wenz reference level for high traffic, for at least 75% of the time within the first 200 metres of the water column. Given the good propagation of lower-frequency sounds, such as marine traffic noise, the size of a ship's acoustic footprint (> 20 km), the travel speed (~ 15 knots) and the frequency of recurrence along the waterway (~ 1/hr), there is not much time between the passage of two consecutive ships during which the sound can reach the low levels of natural sound. In the Estuary, it is estimated that 40% of the infra-sounds regularly emitted by fin whales and blue whales have a high probability of being masked by the noise of maritime traffic after being propagated over just 30 km. Anthropogenic noise is one of the two high-risk threats identified in the Recovery Strategy for the Blue Whale (Beauchamp et al., 2009). However, the relationship of the noise with the intensity of traffic, the types of ships, and their various characteristics needs to be further explored with appropriate data in order to develop a predictive model for the Estuary, which would allow for a better study of the response of marine mammals to different sound levels.

## Issue: Pollutants

Krill is at the base of the food chain and is the primary source of food for a number of organisms and top predators, including the blue whale. It is therefore the main vehicle for transferring lipophilic pollutants to the blue whale. The short lifespan of krill makes it a good indicator of recent changes in environmental quality and in the exposure of predators to persistent organic pollutants (POPs). A research project was conducted to further our knowledge of contamination levels and trends in *M. norvegica*.

Preliminary results show that the different categories of POPs, particularly polychlorinated biphenyl (PCB), polybrominated diphenyl ether (PBDE), several organochlorine pesticides, including dichlorodiphenyltrichloroethane (DDT) and its metabolites, and hexachlorobenzene (HCB), are present at detectable levels in the samples analyzed. Over the course of the period between 1994 and 2009, concentrations of pollutants in *M. norvegica* were either decreasing (e.g. DDT and PBDE) or showed no significant trends (e.g. PCB and HCB). It is expected that the concentrations of PCB, HCB and DDT in the St. Lawrence ecosystem are stable or slightly decreasing, as these POPs have been subject to regulations for more than 30 years and are recycled in the environment. Of all the compounds studied, PBDE is the one that has been most recently subject to regulation. PBDE contamination in *M. norvegica* has decreased significantly. The organism appears to have responded rapidly to PBDE restrictions, which could be a good indicator of recent changes in the quality of the environment.

## Issue: Indicators

An ecological monitoring plan for the future St. Lawrence Estuary Marine Protected Area (MPA) is currently in development. It will address the ecological components of the MPA objectives, threats to these components and the potential effects of these threats. Indicators for every threat and each of their potential effects on the ecological components of the MPA are therefore required. These indicators will be selected based on their ability to assess the achievement of conservation objectives and the effectiveness of the management measures applied within the MPA. The MPA monitoring plan must also include a series of indicators for the state of the physical, chemical and biological ecosystem. These indicators will provide information on the context in which the St. Lawrence Estuary ecosystem is evolving. Based on the results of the ERI, certain indicators will be proposed for this monitoring plan.

The inflow calculated by the hydrodynamic model, coupled with the modelling of the vertical particle position, may serve as indicator for the transport potential of krill from the north-western Gulf to the Estuary. Wind monitoring in the Sept-Îles region may be another indicator of the presence of an inflow event at Pointe-des-Monts. However, development of knowledge on abundance control (e.g. reproduction, recruitment, mortality) and horizontal distribution of krill (e.g. availability of aggregations at the Pointe-des-Monts valve) is required in order to find a real indicator of krill transport in the Estuary.

Additionally, identifying the causes of mortality of marine mammals from beaching data is important as a biological indicator and as a management tool for evaluating the effectiveness of conservation measures.

Lastly, contamination of *M. norvegica* by persistent organic pollutants (POPs) appears to be a good indicator of recent changes in environmental quality. The short lifespan of krill also makes it a good indicator of recent changes in environmental quality and in the exposure of predators to POPs.

## Issue: Use of the ecosystem approach

Implementation of the St. Lawrence Estuary ERI was based primarily on the importance of an ecosystem-based and/or integrated approach to better support ecosystem management, as outlined in the document “A New Ecosystem Science Framework in Support of Integrated Management.” In order to apply this approach in the context of the ERI, a definition of the ecosystem approach for the Science Sector was developed in the Quebec Region and used to guide a scientific planning process involving internal and external clients and MLI scientists. The result was a multidisciplinary research program subject to a formal process for the provision of scientific advice in view of providing input for answers to management issues.

The program integrated research work and ongoing monitoring with existing available information and new work designed to fill certain significant knowledge gaps. Associating the initiative with other programs with related or similar objectives (centres of expertise for Science and Oceans, Health of the Oceans (HOTO), the *Species at Risk Act*; NSERC; zonal and regional monitoring) led to the creation of important financial levers, which promoted complimentarily between initiatives and optimization of affected resources. It also facilitated the optimization of logistical aspects essential to the initiative's success, particularly sea research surveys.

## CONCLUSION

The St. Lawrence Estuary is a diversified, dynamic and complex environment where the evolution of its components is influenced by various environmental or anthropogenic forcing mechanisms. As for the primary objective of this component of the ERI, the various projects have allowed us to draw conclusions on the processes affecting the presence of krill and the attraction of blue whales to the Estuary. In principle, it could be supposed that the abundance of krill in the Estuary was determined both by its production (reproduction, survival, recruitment, etc.) and its transport via the general circulation pattern of the water masses. The aspect of krill production was not studied as part of the ERI. However, important and innovative results clarified the conditions of the hydrodynamic exchanges between the north-western Gulf and the Estuary, and demonstrated the significance of species behaviour (e.g. distribution and vertical migration behaviour) for krill transport. The exchanges between the Estuary and the Gulf follow a general pattern that is more or less consistent from year to year, but the analysis also showed the importance of sporadic and unpredictable phenomena, such as storms, in the region. The distribution of krill aggregations within the Estuary is also influenced by circulation patterns and varies greatly by season. Significant aggregations are observed at the head of the Laurentian Channel, as well as along the Gaspé Peninsula and the north cost between Pointe-des-Monts and Sept-Îles. The quantity of krill does not appear to be a limiting factor in the Estuary, even though the blue whale's competition for this resource ranges from secondary producers (other microzooplankton) to top predators (fish, whales). It could therefore possibly support higher consumption levels. These ERI results lead us to interpret the blue whale's "food habitat" in the Estuary as being a dynamic spatial and temporal phenomenon that covers the entire period of the species' presence. As a result, it is difficult to propose an ecosystem-based indicator to predict the quality of this habitat. However, it is possible to develop an indicator of the abundance of krill, taking into account atmospheric forcing mechanisms conducive to exchanges between the Estuary and the Gulf, and current transports between the two basins, estimated using numerical modelling.

## SOURCES OF INFORMATION

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