Marine Policy 36 (2012) 1221–1233

Contents lists available at SciVerse ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

The role of the International Maritime Organization in reducing vessel threat to whales: Process, options, action and effectiveness

Gregory K. Silber [a,*], Angelia S.M. Vanderlaan [b,c], Ana Tejedor Arceredillo [d], Lindy Johnson [e], Christopher T. Taggart [b], Moira W. Brown [f,g], Shannon Bettridge [a], Ricardo Sagarminaga [d,h]

[a] Office of Protected Resources, NOAA National Marine Fisheries Service, 1315 East West Highway Silver Spring, MD 20910, USA
[b] Department of Oceanography, Dalhousie University, Halifax, NS, Canada B3H 4R2
[c] Fisheries and Oceans Canada, St. Andrews Biological Station, 531 Brandy Cove Road, St. Andrews, NB, Canada E5B 2L9
[d] KAI Marine Services, Nalón, 16, La Berzosa, 28240 Hoyode Manzanares, Madrid, Spain
[e] General Counsel for Office of International Law, National Oceanic and Atmospheric, Administration, 14th & Constitution, N.W., Washington, DC, 20230, USA
[f] New England Aquarium, Boston, MA, 02110, USA
[g] Canadian Whale Institute, Box 410, Wilson's Beach, NB, Canada E5E 1Y2
[h] ALNITAK Marine Environment Research Center, Nalón, 16, La Berzosa, 28240 Hoyode Manzanares, Madrid, Spain

ARTICLE INFO

Article history:
Received 24 June 2011
Received in revised form
6 February 2012
Accepted 11 March 2012
Available online 15 May 2012

Keywords:
International Maritime Organization
Whale
Vessel
Ship
Strike
Risk

ABSTRACT

Ocean-going vessels present a measurable threat of lethal collision with many marine species worldwide, notably large whale species of which many are endangered. Various modifications to conventional vessel operations have been recently used to reduce the threat. Some of the modifications have been instituted by coastal states as a result of their adoption by the International Maritime Organization (IMO) — a specialized agency of the United Nations that is the recognized authority for international maritime shipping interests and their safety of navigation at sea. We describe the processes through which coastal states can approach the IMO to seek review and adoption of environmental conservation proposals involving international shipping. We also provide a description of vessel navigation modifications in specific geographic areas where IMO-adopted measures to protect large whales have been implemented — there are only 10 such cases and we describe each. We then address the methods that can and have been used to assess the effectiveness of such measures. As weighed against the goals of the modifications by estimating the ensuing reduced risk to whales, actions taken are generally regarded as being successful in reducing the risk, but to varying degrees. We conclude that the IMO can be a powerful entity in providing solutions to a range of marine environmental and conservation problems. When used in concert with related efforts such as mariner education, the IMO, and the range of navigational measures available to it, is an effective forum through which coastal states can pursue large whale conservation objectives without unduly compromising the activities of shipping interests.

Published by Elsevier Ltd.

1. Introduction

Worldwide, a number of marine species including sea turtles [1,2], manatees [3,4], small whales [5], and all large whales [6,7] are killed or injured by vessel strikes. As of 2007, there were ~750 records of vessels striking large whales worldwide [8]. This represents a minimum count as an unknown number of vessel strikes go undetected or unreported. When whale carcasses are recovered and examined, the cause of death is often indeterminate [9,10], due, for example, to advanced decomposition or no external evidence of a vessel strike. For some endangered species, such as the North Atlantic right whale (*Eubaelana glacialis*), vessel strikes are a measurable impediment to the recovery of the species [11,12]. A high proportion of dead right whales show signs attributable to vessel strike including severe lacerations, broken bones, internal hemorrhaging and other lethal forms of blunt trauma [9,13].

Abbreviations: AIS, Automatic Identification System; AMVER, Automated Mutual-Assistance Vessel Rescue System; ATBA, Area To Be Avoided; CD, Compact Disc; DGMM, Dirección General de la Marina Mercante (Directorate General of the Merchant Marine); ECAREG, Eastern Canada Vessel Traffic Services Zone Regulations; GT, Gross tonnage; IMO, International Maritime Organization; INMARSAT, International Marine/Maritime Satellite; ICOADS, International Comprehensive Ocean-Atmosphere Data Set; IUCN, International Union for Conservation of Nature; MEPC, Marine Environment Protection Committee; MSC, Marine Safety Committee; MSR, Mandatory Ship Reporting systems; NAV, Sub-Committee on Safety of Navigation; NMFS, National Marine Fisheries Service; NOAA, National Oceanographic and Atmospheric Administration; SOLAS, International Convention for the Safety of Life at Sea; TSS, Traffic Separation Scheme; USA, United States of America; USCG, United States Coast Guard; VOS, Voluntary Observing Ships

* Corresponding author. Tel.: +1 301 427 8485.
E-mail address: greg.silber@noaa.gov (G.K. Silber).

0308-597X/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.marpol.2012.03.008

Table 1
Table of text-referenced proposals submitted by Member States and the dates considered and approved/adopted by the Sub-Committee on Safety of Navigation (NAV), the Marine Safety Committee (MSC), or Marine Environment Protection Committee (MEPC) and the date proposed actions were implemented by the Member State.

Text reference	Proposals submitted/adopted by IMO	Member State	NAV	MSC	MEPC	Implemented
2.1	Report to MSC-IMO: vessels striking right whales	USA	–	–	June 1997	Information 1997
2.2	Mandatory Ship Reporting (MSR): east coast	USA	July 1998	December 1998	–	July 1999
2.3	Traffic Separation Scheme (TSS): Bay of Fundy	CANADA	April 2002	December 2002	–	July 2003
2.4	Traffic Separation Scheme (TSS): Cabo de Gata	SPAIN	June 2005	May 2006	–	December 2006
2.5	Traffic Separation Scheme (TSS) and Recommendatory Speed: Strait of Gibraltar	SPAIN	March 2006	December 2006	–	July 2007
2.6	Traffic Separation Scheme (TSS): Boston	USA	July 2006	December 2006	–	July 2007
2.7	Recommendatory Area To Be Avoided: Roseway Basin	CANADA	April 2007	October 2007	–	May 2008
2.8	Traffic Separation Scheme (TSS): Boston	USA	March 2008	July 2008	–	June 2009
2.9	Recommendatory Area To Be Avoided: Great South Channel	USA	March 2008	December 2008	–	June 2009
2.10	Guidance document: Measures to reduce ship strikes with cetaceans	USA			August 2008	Information July 2009

The occurrence and severity of vessel-strike threat to whale populations in a number of regions around the world has made strike threat an emerging conservation issue, particularly in those places where extensive vessel traffic and whales co-occur. As maritime activities and associated vessel traffic increase, and as some whale populations increase, the rate of lethal vessel-strikes is also likely to increase. Various whale-conservation initiatives have been designed to reduce the threat including vessel routing changes [14–17] and mandatory [18–20] or recommended [14,15] vessel-speed restrictions. Many of these changes were instituted by coastal states following their consideration and subsequent adoption by the International Maritime Organization (IMO).

As a specialized agency of the United Nations, the IMO is the recognized authority for international maritime shipping interests and the safety of navigation at sea. Thus, involvement by the IMO is essential for ensuring internationally coherent solutions to various maritime problems, including threats from vessel traffic to highly mobile and trans-boundary animals such as whales, within and beyond regions of national jurisdiction. In this paper we are typically referring to regions within the Exclusive Economic Zone of a given nation.

Not all research and resource management agencies and personnel engaged in marine conservation are well-versed in the processes involved in approaching the IMO to secure the adoption of marine conservation-oriented proposals relevant to shipping. Each of us has been closely involved in developing proposals to the IMO, and we have direct experience in implementing and analyzing the adopted measures described herein. Thus, our first goal here is to summarize the role and function of the IMO and its process of receiving, reviewing, and adopting proposed changes in vessel navigation that are related to conservation issues. Such proposals are made by a Member State of the IMO, and if adopted, the host nation subsequently implements the change domestically (Sections 1.1, 1.2, below and Appendix A). Our second goal is to detail the vessel strike problem through a description of specific changes to navigation practices that were adopted by the IMO — changes that were designed specifically to reduce lethal vessel strikes to large whales. Worldwide there are only 10 such cases (1.3, 1.4, 2, below and Table 1). We do so to help ensure others are appropriately informed and prepared prior to presenting a vessel related conservational proposal to the IMO. We detail various vessel-navigation modifications of the then existing practices that were adopted by the IMO and subsequently implemented by the host nation. In each case, the goal was to reduce the probability of lethal vessel strikes to large whales without compromising navigational safety at sea. We also review the timelines and processes related to securing an IMO adoption of a navigational modification. Finally, we describe some methods that can be used to assess the effectiveness of such modifications (3, below).

1.1. Role and function of the IMO

Based in London, UK, the IMO was established in 1948 as a specialized United Nations agency, recognized by the International Convention for the Safety of Life at Sea (SOLAS) [21], with responsibility for the safety and security of shipping and the prevention of marine pollution. The IMO Secretariat is headed by the Secretary-General who is appointed by the IMO Council with approval by the Assembly. A principal task of the IMO and its 169 Member States (nations) has been to develop a suite of comprehensive vessel-operation conventions, protocols, codes, and recommendations that address maritime safety, environmental protection, legal matters, technical co-operation, and the efficiency of shipping. The IMO has promoted the adoption of ~40 conventions and protocols and ~800 codes and recommendations. Codes and recommendations provide guidance for framing national regulations and requirements. Though they are not usually binding on the Member States, codes are often implemented through national legislation or regulation. Specialized IMO committees focus on technical work that is used to review and advise other, or 'parent', committees on proposals, or the development and adoption of new policy. Formal cooperation has been established with ~30 inter-governmental organizations and almost 50 non-governmental international organizations. The latter represent a range of maritime, environmental, and legal interests and often have observer status and often participate in the work of the various committees.

1.2. The process: Proposals to the IMO

To secure vessel-navigation regulations or policies, or modifications thereof, from the IMO, a Member State must develop and submit a formal proposal. Only a government, or other affiliated member, may submit a proposal that justifies the need for the proposed action. A proposal must describe the problem, justify the nature of the action proposed to solve the problem, and identify potentially adverse effects such an action might have on maritime interests and on the safety of navigation at sea. Documentation should be provided for the region and problem of interest, the associated nature of the vessel traffic (density, routes used, etc.), the status of neighboring states regarding the region of interest and the proposed action, and existing navigational rules, regulations and (or) policies associated with the region. Proposals related to environmental issues are typically reviewed and endorsed (or not) by IMO committees that may include the Marine Environment Protection Committee (MEPC), the Sub-Committee on Safety of Navigation (NAV), and the Marine Safety Committee (MSC). The latter two are engaged when proposals involve navigation and marine safety.

In all cases, the solicitation of an IMO endorsement for a proposed action must be founded on the soliciting Member State having already endorsed the proposal. As most proposed actions relating to navigation lie partly or wholly within territorial waters or Exclusive Economic Zones [22], IMO endorsement is generally preceded or followed by action involving rule making authorities and regulatory instruments or policies such as declarations or legislation. As in the actions taken and measures discussed below, proposals emanating from the United States of America (USA) require interagency clearance and are submitted to the IMO by the US Coast Guard (USCG) on behalf of the USA government. In Canada, responsibility lies with Transport Canada, and in Spain with the Dirección General de la Marina Mercante (DGMM).

1.3. The problem: Vessels striking large whales

To our knowledge, 10 specific actions have been endorsed by the IMO to reduce the likelihood of vessels striking and killing or injuring large whales, and with one exception, they are limited to four whale species and three geographic regions: the North Atlantic right whale (hereafter, right whale) along the eastern seaboard of the USA and the Scotia-Fundy region of Canada, and the fin (*Balaenoptera physalus*), sperm (*Physeter macrocephalus*), and long-finned pilot (*Globicephala melas*) whales in the western Mediterranean Sea. In each case, we provide a brief summary of whale occurrence and distribution in these regions and the magnitude of the threat they face from vessel strikes. The exception is a general, but relevant, international guidance document that addresses vessel strikes to whales.

1.4. Northwest Atlantic

The right whale is a large baleen whale and is among the most endangered of the large whales. It was severely exploited during commercial whaling and is listed as 'endangered' by the International Union for the Conservation of Nature, (IUCN) [23], the USA Endangered Species Act, and the Canadian Species at Risk Act. Although estimates of abundance vary, most authors agree the western North Atlantic population consists of ~300–450 individuals.

Right whales inhabit the coastal shelf-waters of eastern North America, although a few oceanic movements are documented. Most individuals migrate annually between wintering, calving, and nursery areas off the southeastern USA and summer feeding habitats off New England in the USA and in the Bay of Fundy and on the southwest Scotian Shelf in Canada. Five primary habitats include the southern calving and nursery grounds off Florida and Georgia, Cape Cod Bay, the Great South Channel east of Cape Cod, the Bay of Fundy, and Roseway Basin [24]. Each of these habitats is intersected by highly concentrated vessel traffic.

Vessel strikes account for 53% of all right whale deaths diagnosed from necropsies [13]. Probability estimates of deaths from vessel strikes, based largely on Moore et al. [9] and Kraus et al. [11], could be as high as 10 individuals in any given year [25]. Of the 50 documented right whale deaths occurring between 1986 and 2005, 19 were attributed to vessel strikes [11]. An average of two or more known North Atlantic right whale deaths and serious injuries from vessel strikes occurred annually for the last decade [10,26]. Based on existing records [7,27], and on a per-capita basis, the right whale is two orders of magnitude more likely to suffer a vessel strike than any other large whale species [28]. Right whale vulnerability to vessel strikes is likely related to their coastal distribution that exposes them to high-density vessel traffic [29] and their apparent lack of avoidance of oncoming vessels [30,31]. The endangered status of the right whale and the magnitude of lethal vessel-strike risk led the governments of the USA and Canada, in concert with various non-governmental organizations, to seek ways to minimize the risk of vessel-strikes to whales.

1.5. Mediterranean Sea

The Mediterranean Sea is one of the most heavily used shipping regions in the world, with over 220,000 vessel (>100 gross tonnage, GT) transits each year. The number of transits is expected to increase three- to four-fold in the next 20 years. Vessel strikes in the region pose a measurable threat to fin and sperm whales, and some smaller whale species [32]. Although whale and dolphin population estimates for the entire Mediterranean are unavailable, areas of high whale concentrations, including fin, sperm, Cuvier's beaked (*Ziphius cavirostris*), long-finned pilot, and killer (*Orcinus orca*) whales are intersected by major shipping lanes.

The IUCN has designated the sperm whale as 'endangered' in the Mediterranean Sea [23] where it ranges throughout the western and eastern basins, and in deep waters adjacent the continental shelf. Sperm whale abundance data are unavailable, though qualitative estimates are in the hundreds and not the thousands [32]. This species is also vulnerable to vessel strikes in the Strait of Gibraltar, the Pelagos Sanctuary, around the Balearic Islands, and off southern Crete.

Fin whales have been designated by the IUCN as 'vulnerable' in the Mediterranean Sea [23] where vessel strikes are considered the primary threat to the species [33,34]. Fewer than 5000 fin whales are believed to inhabit the Sea where they occur primarily in deep offshore waters around Sardinia and Corsica and Balearic islands, in the Gulf of Lion, and in the Alboran Sea. There are notably high concentrations in the Strait of Gibraltar. Fin whale abundance has decreased over the last decade in the Pelagos Sanctuary, an area that includes waters around Sardinia and Corsica islands and the coasts of Italy, Monaco, and France [35]. Although the reasons for the decline are unclear, a Mediterranean-wide population decline in fin whales cannot be discounted [32].

The status of Cuvier's beaked whale is designated by the IUCN as 'data deficient' [23] and it inhabits the western and eastern basins of the Mediterranean and tends to be associated with deep slope, submarine canyons, and escarpment habitats [32]. They also inhabit the Alboran Sea, the Pelagos Sanctuary, and waters off the south coast of Greece. Killer whales, long-finned pilot whales, and Risso's dolphins (*Grampus griseus*) also frequent waters associated with high vessel traffic and are thus vulnerable to vessel strike.

The endangered and vulnerable status of the sperm and fin whales and the general threat of vessel strike to these and the other species listed above has prompted the government of Spain, in collaboration with non-governmental organizations, to identify means to reduce vessel-strike probability.

1.6. Options available to mitigate vessel strikes

There are a finite number of options available to mitigate vessel strikes to large whales within the constraints of a safe and efficient maritime commerce. These include, (a) educating maritime industries about the vulnerability of whales to vessel strikes, (b) providing whale location information to mariners to increase their awareness and preparedness to avoid whales, (c) establishing time and (or) area-specific vessel-speed restrictions to minimize the likelihood of lethality of a strike should it occur, and (d) establishing time and (or) area-specific modifications to vessel-traffic routing to minimize the probability of a strike occurring.

There is little evidence that extensive mariner education, (a), or the provision of whale locations, (b), results in modified mariner behavior with regard to reducing vessel strikes. Both types of information require that mariners receive and heed the advisories provided, choose to take voluntary actions (that may be inconsistent amongst vessel operators), and perhaps engage in avoidance maneuvers (that may not be feasible in all situations) [28,36]. Nonetheless, we suggest it is essential to foster and maintain a constructive flow of information among the various conservation agencies and vessel operators. Building mutual respect and trust between vessel operators and those agencies and organizations engaged in providing such information is crucial to the execution of successful conservation initiatives while also maintaining the safety of navigation at sea. Such relationships may also help foster development of innovative approaches to challenging conservation problems.

There is reliable evidence that vessel speed restrictions, (c), can reduce the forces involved in [29] and the probability of death resulting from [28] a vessel strike. Speed restrictions may limit strike severity, but they may have concurrent negative time-related economic consequences. There is also reliable evidence that modified traffic routing, (d), reduces vessel strike probabilities

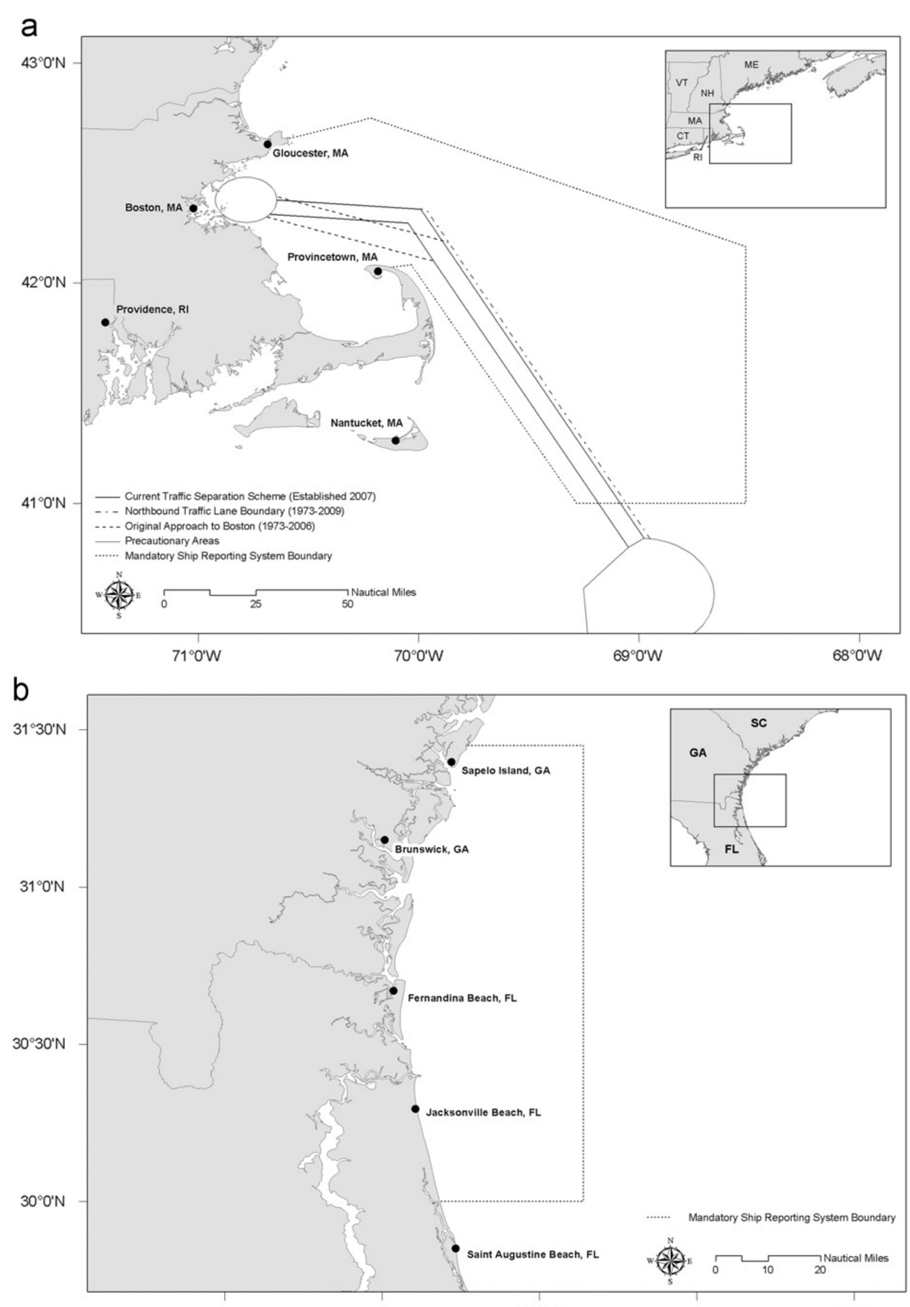

Fig. 1. Right whale Mandatory Ship Reporting systems (MSR) in waters off New England (a) and the southeast USA (b). Also shown is the original and modified Traffic Separation Scheme (TSS) in the approach to Boston (a). The TSS was modified following adoption by the IMO, including a 12 degree shift of the northern leg and a narrowing of both the north-south and east-west legs.

[17,25], though modifications may not be feasible in some regions due to safe-navigation constraints. Nonetheless, eliminating or reducing the extent of vessel and whale coincidence in time and space is assured to reduce the likelihood of a vessel strike and thus it is preferable, where possible, to vessel-speed restrictions. Given the evidence that modified vessel operations can reduce vessel strikes and (or) their severity, it is incumbent upon conservation agencies to draw upon the IMO and its numerous navigation instruments. The global reach of the IMO makes it an optimum forum for considering proposals to minimize vessel strikes to whales.

2. Proposals adopted by the IMO to mitigate vessel strikes

The IMO has been approached 10 times (Table 1) with independent submissions by three nations seeking a reduction of vessel strikes to whales in three geographic regions. Here we summarize these submissions in chronological order of their submission, the actions taken by the IMO, and the actions taken by relevant Member states. To orient the reader – particularly resource management personnel and policymakers – about the suite of navigational instruments available to the IMO, we provide a listing and a brief definition of each in Appendix A.

2.1. Information paper: Vessels striking right whales, USA (1997–1998)

The IMO was first approached about the problem of vessel strikes to right whales in 1997. Recognizing the significance of vessel strikes to the whales, the USA developed and submitted an information paper [37] to the IMO-MEPC in June 1997 [38]. Developed collaboratively by the US Marine Mammal Commission, the National Oceanic and Atmospheric Administration (NOAA) and the USCG, the paper identified and detailed the threat of vessel strikes to right whales. The paper asked that the IMO distribute the paper and called upon IMO member states to inform their respective shipping interests about the issue and provide relevant information on vessel strikes to NOAA's National Marine Fisheries Service (NMFS), the agency responsible for the conservation right whales in the USA. The IMO acted accordingly and this laid the groundwork for the possible and subsequent reduction of vessel strikes under the auspices of the IMO.

2.2. Mandatory ship reporting (MSR): East coast, USA (1998–1999)

In June 1998 the USA followed the 1997 information paper with a proposal to the IMO [39], prepared jointly by the USCG and NOAA, seeking the establishment of two Mandatory Ship Reporting systems (MSR) (Appendix A) in regions of right whale aggregations in USA waters. The systems were to provide information (about whales and their vulnerability to vessel strike) directly to individual vessels in near real-time when they entered the defined regions [40–42]. The proposal had been endorsed by President Clinton in April 1998 [40].

Under the proposed measure, all commercial vessels $\geq$300 GT would be required to report to shore-based stations when they entered either of two regions off the east coast of the USA [39,40] where and when right whales were known to occur: one off the state of Massachusetts (Fig. 1(a)) operating year-round, and one off the states of Georgia and Florida (Fig. 1(b)) operating annually from 15 November through 15 April. Each vessel-crew would be required to report the vessel name, call sign, course, speed, location, destination, and route (waypoints). In return, the vessel would immediately receive updated information concerning right whale locations, as well as procedural guidance to help prevent a vessel strike. Mariners would be advised to consult navigational publications such as the

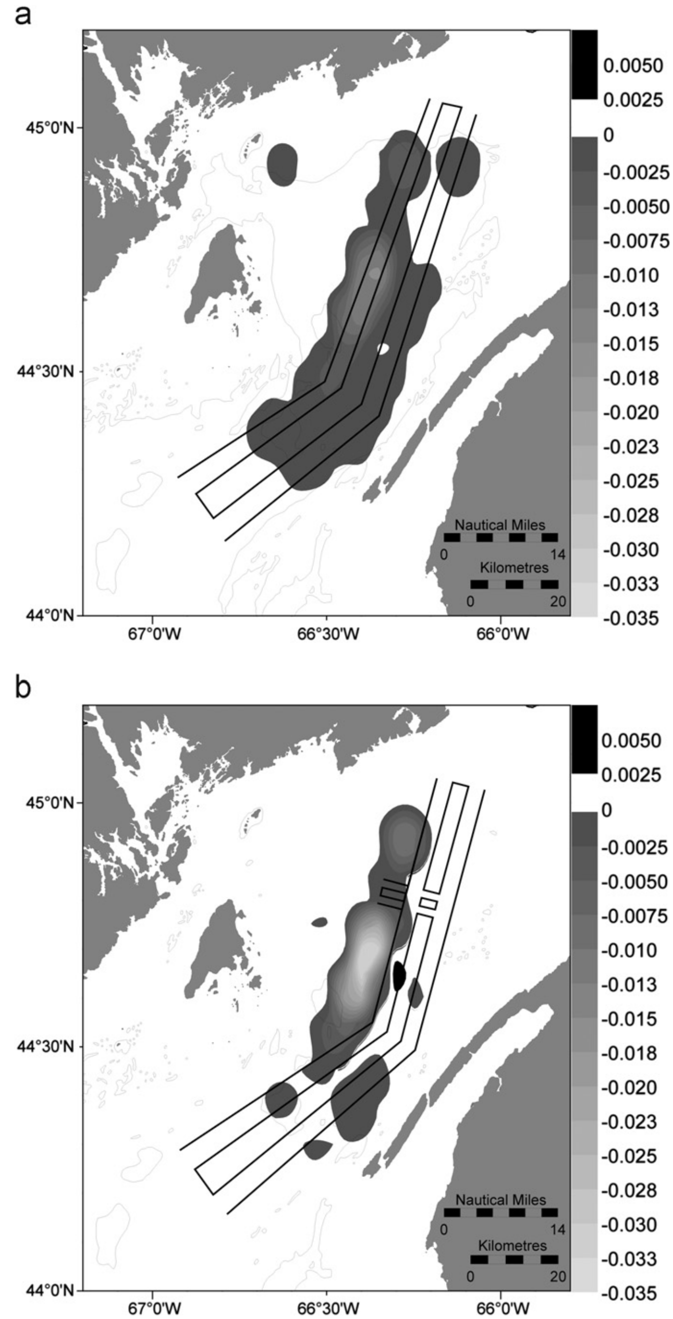

Fig. 2. Standardized (comparable scale) residual risk of lethal collision between a vessel and a right whale associated with the original and amended (solid black line) Bay of Fundy Traffic Separation Scheme (TSS). The original (solid black line) TSS is also shown (b) with a hypothetical 10 knot speed restriction imposed over the entire study area. Negative residuals indicate reduced risk. 100 m isobaths are indicated. Modified from Vanderlaan et al. [16].

US Coast Pilot, Sailing Directions (an international shipping guide), and nautical charts for information on regulations and boundaries of right whale critical habitat. Mariners would be further advised that information placards, CDs, and other educational materials are available from shipping agents, port authorities, relevant state agencies, the USCG, and NMFS. Mariners would also be advised that updated information on right whales locations would be available through the broadcast media, including the USCG Broadcast to Mariners, satellite-linked marine safety broadcasts, and NOAA Weather Radio. The reporting system would affect no other aspect of vessel operation and all two-way communication costs were to be borne by the USCG and NMFS. The primary communication system is via INMARSAT-C (satellite) for the majority of vessels, and thus the information would be received in near real-time. In return, the MSR systems would provide NMFS with data concerning number and operations (e.g., courses, speeds etc.) of vessels transiting the region [43]. The data would be used to assess and consider additional or modified mitigation options (e.g., [44,45]).

The two MSR systems, reviewed by the NAV for recommendations to the MSC [41], were approved in July 1998, and adopted by the MSC in December 1998 [46]. Following adoption by the IMO, the systems became effective on 1 July 1999 and have remained in effect as designed to the present. This was the first time an IMO-endorsed measure was used to protect a particular marine species [41]. Subsequently, the USCG issued a Final Rule in the USA Federal Register codifying the systems by modifying the USA Code of Federal Regulations [47] and the MSR areas were incorporated into USA nautical charts by NOAA.

2.3. Traffic Separation Scheme (TSS): Bay of Fundy, Canada (2002–2003)

A TSS (Appendix A) was established in the Bay of Fundy, to organize traffic through fishing grounds and to enhance the safety of vessels traveling to and from the entrance to the Bay and the Port of Saint John, New Brunswick. The TSS was originally adopted by the IMO in 1982 [48] and established in June 1983 (Fig. 2(a)). However, the outbound lane of the TSS intersected a Right Whale Conservation Area in the Grand Manan Basin that had been created to identify an area in which summer/fall right whale aggregations occur (2.7 below). Therefore, non-governmental members of the North Atlantic Right Whale Recovery Implementation Team successfully petitioned Transport Canada to submit a proposal to the IMO to amend the TSS with the goal of reducing the probability of vessel strikes in the Basin [49,50]. The proposal was considered by the IMO-NAV in July 2002 [51], approved and forwarded by NAV to the IMO-MSC in July 2002, and adopted by the MSC in December 2002 [52]. The TSS was modified on 1 July 2003. The amendment included a relocation of the northern extent of the TSS by 3.9 nm to the east with a re-alignment toward the Port of Saint John, and the establishment of an entry/exit TSS junction north of the Basin for traffic navigating to and from the Canada and USA ports to the west (Fig. 2(a)). The change was published in Notices to Mariners and incorporated into Canadian Hydrographic Services nautical charts.

2.4. Traffic Separation Scheme (TSS): Cabo de Gata, Spain (2005–2006)

The Cabo de Gata (Cape Gata) region of the western Mediterranean is situated in the Alboran Sea bordered by Spain, Algeria, and Morocco. The coastal area is protected under Spanish law as a marine reserve, a nature reserve, and site of European interest (Natural Park of Cabo de Gata–Nijar). It is also a Special Area of Conservation for Cetaceans in the Mediterranean Sea [32,53,54]. However, the area was intersected by the Cabo de Gata TSS, established in 1998 [46], that annually directed $\sim$35,000 vessel transits to and from the Strait of Gibraltar and ports along the northern coast of the Mediterranean (Fig. 3). The TSS also intersected rarely-used fishing grounds until around 2001 when increased bottom trawling activities increased the risk of vessel collisions. At the same time, maritime traffic authorities became increasingly concerned with high traffic volume in relation to the sensitive coastal and marine habitats designated as Sites of Community Importance (European Union Habitat Directive) and in relation to the numbers of cetacean species and loggerhead sea turtles (*Caretta caretta*) that occur in the region.

In May 2005 the Spanish DGMM submitted a proposal to the IMO that was designed to first reduce the risk of collision between vessels using the TSS and the increased numbers of fishing vessels, and second to enhance environmental protection. The proposal sought a modification of the Cabo de Gata TSS such that it would lie 20 nm seaward of the Cape (Fig. 3). The proposal was adopted by the NAV [55], then by the MSC in the same year [56], and came into effect on 1 December 2006 [57] along with a publication in Notices to Mariners and incorporation into nautical charts [58].

2.5. Traffic Separation Scheme (TSS) & recommended speeds: Strait of Gibraltar, Spain (2006–2008).

The 7-nm (13 km) wide Strait of Gibraltar provides the only direct connection between the Mediterranean Sea and the Atlantic Ocean.

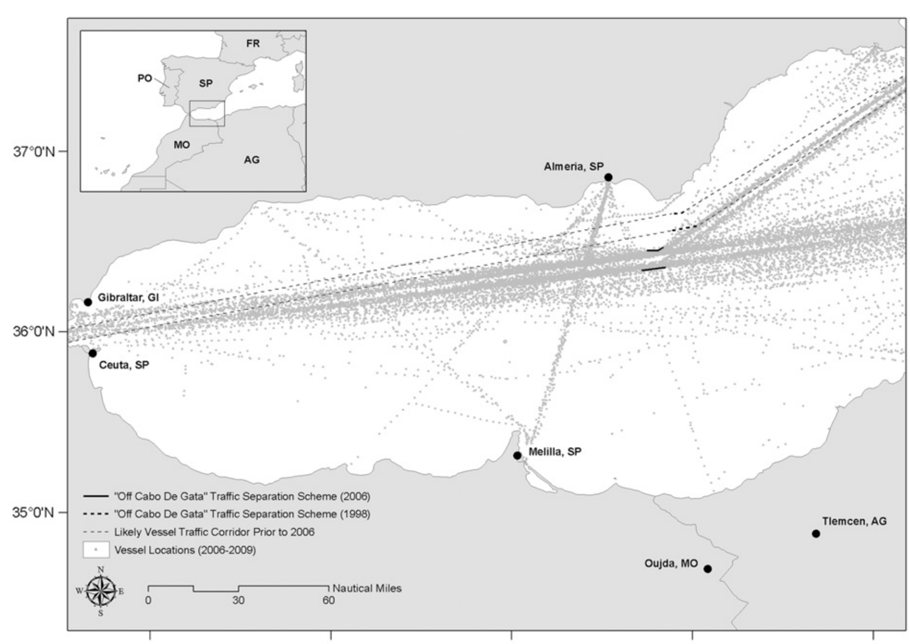

Fig. 3. The original and the modified Alboran Sea Traffic Separation Scheme (TSS). Vessel locations (derived from AIS studies) are shown in the revised TSS.

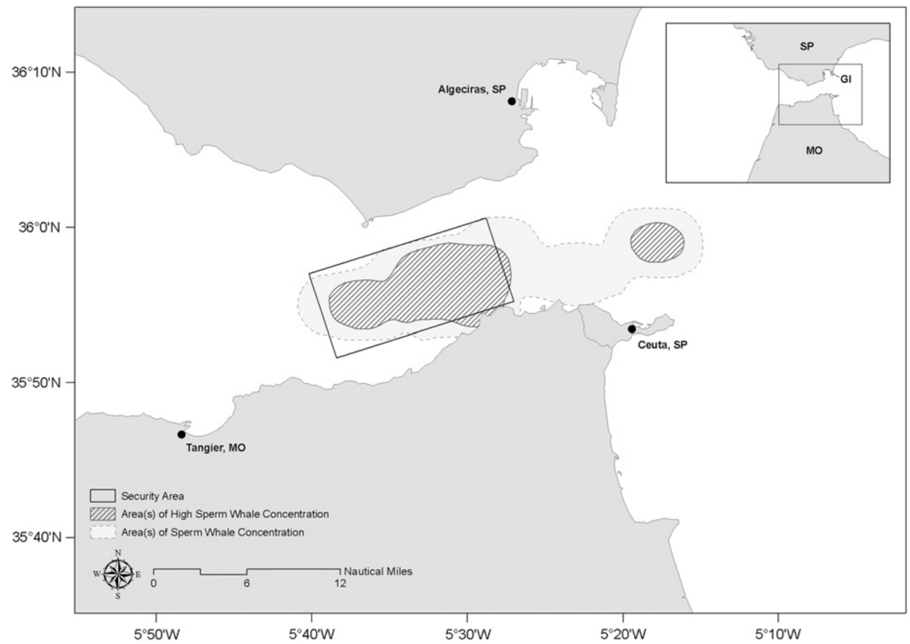

Fig. 4. Sperm whale sightings and security area as proposed to the IMO in the Strait of Gibraltar.

Approximately 110,000 voyages occur in the Strait each year connecting numerous North African and Middle Eastern ports with those in North, Central, and South America. This, along with passenger and fast ferries that transport ~4,000,000 passengers per year, private yachts, whale-watching and fishing vessels, the traffic volume makes this a region of major vessel-strike risk to whales. Migrating and feeding aggregations of fin and sperm whales occur in this area in relatively high numbers [59]. Sperm whale foraging aggregations occur in the region in January through May (Fig. 4) and early summer and winter fin whale migration routes intersect commercial shipping and passenger ferry routes, including the Gibraltar TSS and contiguous waters.

In March 2006, following the construction of the large industrial port Tangier-Med, Morocco (Fig. 4), built to accommodate transport of passengers and cargo to and from northern Africa, Moroccan and Spanish maritime authorities proposed to the IMO a re-configuration of traffic lanes in the Strait of Gibraltar [60] (Fig. 4). However, this modification conferred with it an increased risk of collision by intensifying traffic through key sperm whale aggregation areas. Recognizing the threat to sperm whales, the Spanish Ministry of the Environment made a request to the Spanish Maritime Authority to include in the 2006 proposal a vessel exclusion zone to limit traffic in areas of sperm whale occurrence. Given the complexity and volume of shipping in this TSS, and the fact that the attempt to include the exclusion zone provision was made during the review process, the proposal to modify the TSS was endorsed by the NAV, but the accompanying proposal for an exclusion zone was rejected. The proposal to reconfigure the TSS was therefore approved (without incorporation of the exclusion zone) by MSC in December 2006 [61], as initially submitted to the NAV.

Seeking to reduce the new threat to sperm whales created by the newly established TSS, the Spanish Maritime Authority subsequently sought to establish a security area where vessels were advised to limit maximum speed to 13 knots (this speed limit was based on analysis by Laist et al. [7]), and to navigate with particular caution. Following review by the IMO, 13-knot speed recommendations were published by the IMO through the MEPC, added to International Nautical Charts, and disseminated as a Notice to Mariners (published on January 2007 by the Spanish Navy Hydrographical Institute). In so doing, this measure became the first vessel speed recommendation instituted in a TSS for the purposes of cetacean conservation. Vessel monitoring studies are underway to assess use of the TSS and compliance with the 13-knot maximum speed advisories (see below for further discussion of this).

The approach taken and outcomes of the Cabo de Gata TSS (2.4, above) and Tangier-Med TSS scenarios provide an interesting comparison as well as insight into the IMO. The Tangier-Med proposal (and subsequent attempts to provide recommended speed limits) suffered from a lack of intra- and inter-national coordination and communication. This proposal was likely technically deficient, as well. The Tangier-Med situation also lacked consideration of environmental issues (e.g., estimates of vessel strike risks) sufficiently early in the process of establishing/modifying shipping lanes. In contrast, the successfully endorsed Cabo de Gata TSS proposal did not have these shortcomings. In addition, in contrast to IMO adoption of specific routing measures like a TSS reconfiguration, the IMO's involvement in matters regarding vessel speed, as in this case, is likely tentative particularly in locations with significant trade routes and high traffic volume.

2.6. *Traffic Separation Scheme (TSS): Boston, USA (2006–2007)*

A TSS in waters off New England, established in 1973 [62] to manage traffic navigating to and from Boston, intersected an area repeatedly inhabited by high concentrations of right whales (and other large whale species) that migrate along the coast and in and out of Cape Cod Bay. In April 2006, the USA submitted a proposal [63] to the IMO to narrow and modify the location of the east-west leg of the TSS where it joined the north-south leg (Fig. 1(a)), thereby reducing the probability of vessel strikes by an estimated 58% and 81% in that area for right and other large whales, respectively [44]. The proposal identified adverse effects to vessel operators (increasing the voyage by about 3.8 nm) and provided an analysis of benefit to right whales in terms of vessel strikes based on a USCG Port Access Route Study that underwent inter-agency clearance and public consultation [42,64]. The proposal was approved by the NAV in July 2006, forwarded to the MSC, and adopted by the IMO in December 2006. The amended TSS went into effect on 1 July 2007 [57]. The amendment was added to NOAA navigational charts and the USCG updated its list of offshore traffic separation schemes and precautionary areas in the USA Code of Federal Regulations.

2.7. Area to Be Avoided: Roseway Basin, Canada (2007–2008)

In addition to the Grand Manan Basin in the Bay of Fundy, right whales also aggregate annually in the Scotian Shelf's Roseway Basin that is intersected by vessels transiting through Shelf waters and to and from the approaches to New York City and other ports in the USA (Fig. 5). The traffic posed a measurable risk of lethal vessel strike to right whales [16,64]. In 2006, non-governmental members of the North Atlantic Right Whale Recovery Implementation Team once again successfully petitioned the regional and national Canadian Marine Advisory councils (Transport Canada) to support a proposal [65] to establish an Area To Be Avoided (ATBA) in the Roseway Basin region. Transport Canada subsequently proposed creation of the ATBA to the IMO in July 2007 [66] when it was approved by the NAV, forwarded to the MSC, and adopted by the IMO in October 2007; the ATBA was implemented in May 2008. The ATBA is recommendatory for all vessels $\geq$ 300 GT and is in effect annually from 1 June to 31 December. The Canadian Hydrographic Service incorporated the ATBA into nautical charts, the standard notifications to mariners were issued, and Caution-to-Mariners placards were distributed to a variety of shipping interests by the non-governmental organization Canadian Whale Institute.

2.8. Traffic Separation Scheme (TSS): Boston, USA (2008–2009)

In March 2008 the USA submitted a proposal to the IMO for a narrowing of the north-south leg of the previously modified Boston TSS (2.6 above) to further separate vessels and right whale aggregations near the TSS [45], and to make the leg consistent in width with the previous narrowing of the east-west leg. The proposed amendment was approved by the NAV in March 2008 [67] when it was forwarded to the MSC, adopted by the IMO in July 2008 [68], and it went into effect in June 2009. As above, Member States and shipping interests were notified and changes were incorporated into navigational charts.

2.9. Area To Be Avoided: Great South Channel, USA (2008–2009)

In summer and autumn, right whale feeding aggregations are persistent in the Gulf of Maine's Great South Channel, an area that includes the existing MSR area (2.2. above), the Boston TSS (2.6 and 2.8), and two heavily used but unspecified routes [43,45] with generally NW-SE and NE-SW orientations (Fig. 6). Given the elevated risk of lethal vessel strike in the region [69], the USA submitted a proposal to the IMO in March 2008 seeking the establishment of an ATBA in the Great South Channel [70]. The proposal would also encourage increased use of the amended Boston TSS. The proposal was approved by the NAV in March 2008, forwarded to the MSC, adopted by the IMO in December 2008, and implemented in June 2009 [17]. The ATBA is recommendatory for all vessels $\geq$ 300 GT and is in effect annually from 1 April through 31 July. As in all cases above, the ATBA was incorporated into nautical charts and standard notifications to mariners were issued.

2.10. Guidance document: Measures to reduce ship strikes with cetaceans, USA, Spain, France, Italy, and Monaco (2008–2009)

In August 2008 the USA provided the IMO with a draft guidance document [68] that identified ways to minimize the risk of vessel strikes of cetaceans globally. In October 2008, the MEPC agreed to invite delegations to provide comments on the draft for eventual approval by the MEPC [71]. In May 2009, Spain, in cooperation with France, Italy, and Monaco, presented a supporting paper [72] with a focus on the Mediterranean Sea. The Guidance Document was approved in July 2009 and it was issued as an MEPC circular with an invitation for member states to bring the circular to the attention of all interested parties, including administrations, recognized organizations and shipping interests. The Document identifies general principles for member states to monitor, assess, and mitigate vessel-strike risk in their waters. These principles, while stressing that maritime safety is paramount, include the scientific assessment of shipping and the affected cetacean populations, science-based risk mitigation, monitoring the effectiveness of any vessel strike reduction initiative, and mariner education and outreach programs. Cooperation at an

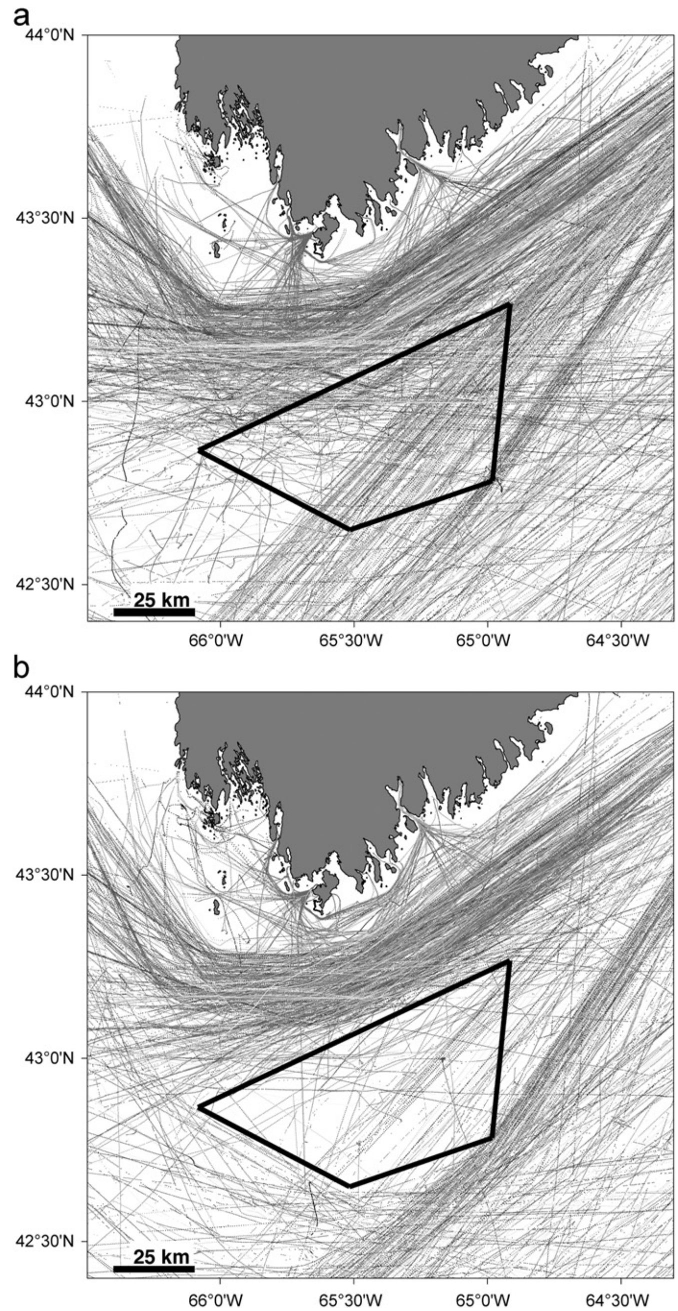

Fig. 5. The Roseway Basin Area To Be Avoided (ATBA) (black polygon) in (a) and (b) and vessel tracks through the region from 15 June to 31 October 2007 (a) and from 1 June to 31 October 2008 (b) prior to and following implementation of the ATBA, respectively. Modified from Vanderlaan and Taggart [17].

international level is also identified including coordination with relevant international fora such as the International Whaling Commission that is now addressing vessel strike reduction.

3. Assessing the effectiveness of measures to reduce vessel strikes

A conservation initiative, no matter how well-intentioned, has limited value unless it can be shown to have attained its objectives. The relative effectiveness of a routing measure for instance should be realistically weighed against the allocation of resources needed for implementing and monitoring it and used in assessing the need to improve or possibly abandon the measure. When it comes to the reduction of lethal vessel strikes to whales, most studies to date (as discussed in Sections 3.1–3.3, below) have focused on quantifying vessel operations in response to the measure, determining biological effectiveness (i.e., observed reductions in vessel strike incidents), and risk reduction estimates. However, such assessments may be confounded by variables that include shifts in vessel-traffic density and patterns; seasonal, annual, and decadal changes in whale abundance and distribution; inconsistent strike detection 'effort' and reporting; and the availability of the necessary whale, vessel and other relevant data. These limitations notwithstanding, several data sources, technologies, and analytical methods are available to assess risk reduction.

With regard to right whales in USA waters, Silber and Bettridge [73] identified four issues related to assessing the effectiveness of federal regulations that restricted vessel speed in certain locations [18]: (a) mariner education, (b) assessing economic impact that may result from the regulation, (c) measuring the response by mariners to the regulation, and (d) quantifying changes is various whale-related variables and parameters. Of these, (a), (c), and (d) are most relevant here.

Raising mariner awareness, (a), about the impact of vessel-strike deaths on whale populations is worthy of considerable attention because mariners cannot be expected to help reduce strikes if they have no knowledge of the problem or the relevant actions they could take. Given the opportunity, mariners may help offer solutions, and their engagement helps build trust and cooperation. Outreach programs also offer avenues for encouragement. There are a number of ways to educate mariners and such approaches are identified elsewhere [e.g., 15,74].

3.1. Quantifying vessel navigation patterns

Quantifying vessel operations (e.g., routes and speeds), as a measure of mariner adherence to required or voluntary conservation measures, is essential to both designing vessel-related initiatives and for subsequently evaluating their relative success. Various data sources are available that can be used to characterize vessel speed, traffic density etc. in time and space. Until recently, the most available vessel-navigation data included the International Comprehensive Ocean-Atmosphere Data Set (ICOADS, National Center for Atmospheric Research, Boulder, Colorado USA) that includes data derived from a fleet of Voluntary Observing Ships (VOS). The 'fleet' is represented by $\sim$4000 commercial vessels drawn from the world fleet of $\sim$45,000 vessels [75–77]. These data are global in distribution and provide information daily across a decades-long time series. However, they represent $\sim$10% of the world fleet and the spatial resolution is 0.1 degree (approximately 6 nm). Similar national or regional data include the Automated Mutual Assistance Vessel Rescue System (AMVER) [78], the now disbanded Eastern Canada Vessel Traffic Services Zone Regulations (ECAREG) [16], radar tracking [16], and the MSR systems [43]. There are also globally distributed data that can be derived from the long-range identification and tracking (LRIT) of the world fleet as instituted by the IMO under the SOLAS convention [79], though such data are not readily available outside certain governmental regulatory agencies.

Recently, readily- and economically-obtained vessel Automatic Identification System (AIS) information has been used to quantify vessel operations. The AIS employs a VHF (161.9765 mHz and 162.025 mHz) ship-to-ship and ship-to-shore messaging system that is required on all international vessels $\geq$300 GT and cargo vessels $\geq$500 GT [80]. In the Vessel Traffic System areas of the USA, AIS is also required on all self-propelled commercial vessels of at least 65 feet and some passenger and towing vessels.

Transmitted AIS signals provide static (e.g., ship name, call sign, hull specifications) and dynamic (e.g., vessel location, speed) voyage-related information [81]. Initially designed to enhance vessel safety, AIS is now being used to characterize vessel traffic patterns [82], assess contributions of ocean-going vessels to underwater noise [83], and quantify vessel-operator compliance with mandatory [84] and recommendatory vessel strike reduction measures [17]. Vessel track and speed analysis can be quite precise given AIS signals are transmitted numerous time each minute [84]. AIS receivers suffer from line-of-sight range-limitations (ca. 45 km, depending on height of the receiver and certain other, e.g., meteorological, conditions) [84] and thus require a network of coastal towers for regional coverage. Development of more advanced satellite-mediated AIS systems may be a reality in the foreseeable future, but their status remains uncertain.

AIS technologies have been used specifically to assess mariner response to the IMO-endorsed measures described in this paper. For example, responses have been quantified with regard to the ATBA in Roseway Basin in which vessel tracks exhibited clear course changes to avoid the area (Fig. 5(a) and (b)), and in the case of the USA Great South Channel ATBA, a shift toward use of the TSS servicing Boston, as intended, has resulted from the placement of the ATBA. Similarly, AIS-based studies indicate clear differences in vessel traffic patterns before and after the November 2006 shift of the Cabo de Gata TSS — full compliance with the modified TSS has occurred (Fig. 3). In addition, surveys indicate that several whale species are occurring primarily north and south of these shipping lanes, suggesting that the re-positioning of the Cabo de Gata TSS has lowered the risk of vessel strikes.

In contrast, AIS monitoring of the Gibraltar Strait TSS indicates that mariners are not adhering to the 13 knot recommended vessel speed limit. Low adherence levels are likely due to irregular (and limited geographic range of) broadcasts about the advised speed limits and because they were merely 'noted' by the IMO rather than being endorsed as a specific measure. In addition, routing measures are common and accepted actions for the IMO, but speed restrictions are not — thus, the latter likely are not readily recognized by mariners. In an analogous situation involving domestically-implemented vessel speed limit requirements in USA waters (mandatory in this case) [18] low initial compliance was observed in which over 60% of vessel transits in the first 12 months exceeded the 10 knot limit [84].

On the whole, results of vessel monitoring studies help illustrate both the potency of IMO involvement in establishing new vessel operating practices when routing measures are involved, and the difficulties inherent to invoking speed limits. Although a viable tool for reducing vessel strikes [18,25], use of vessel speed restrictions may encounter hurdles in part because they are rarely employed or may be unfamiliar for some maritime communities, at least as far as vessel-strike reduction purposes are concerned.

3.2. Assessing the biological effectiveness of vessel collision reduction measures

Decreased vessel strikes events is the ultimate goal of vessel-strike reduction measures and enumeration of a reduction in strikes

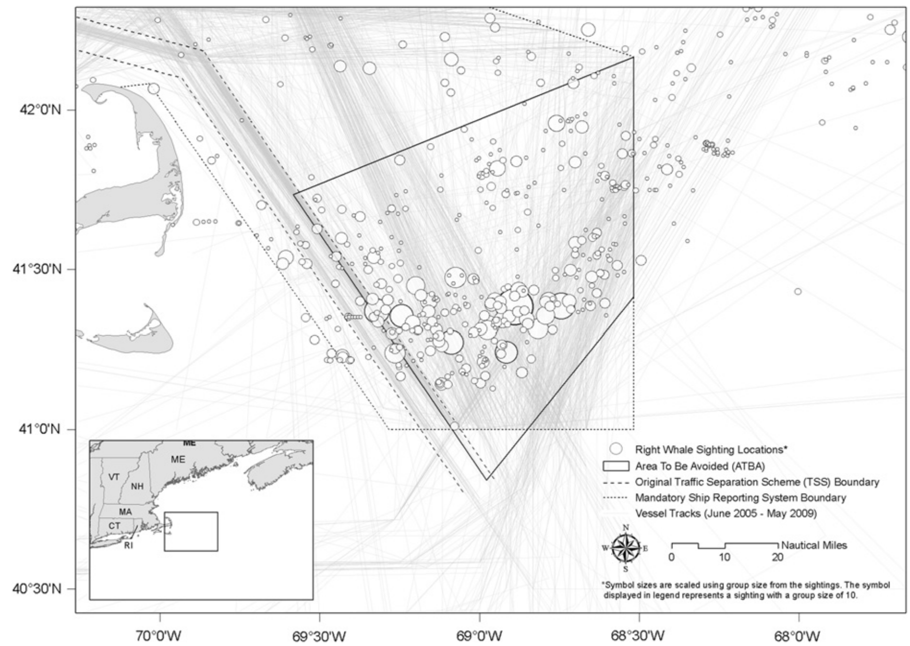

Fig. 6. North Atlantic right whale sighting locations January 1999–July 2005 and vessel traffic patterns June 2005–May 2009 in the area that later became the Great South Channel Area To Be Avoided. Vessel data were derived from the Mandatory Ship Reporting system data. Right whale sighting information provided courtesy of NOAA's Northeast Fisheries Science Center's aerial survey program.

(e.g., documenting fewer whale deaths, or quantifying population growth, the later being at least partly attributable to fewer mortalities; item d in Section 3, above) is one direct measure of relative success. However, quantifying such reductions may not be easily accomplished because not all strikes are observed or reported. Pace [85] used one biological metric in assessing the effectiveness of vessel speed limits: time elapsed between subsequent known vessel strike deaths or serious injuries, both before and after the enactment of a specific measure (but, this has not been applied to the IMO-endorsed measures discussed here). This approach helps avoid the pitfalls of trying to assess trends in absolute numbers of whale-strike events given they are rarely and incompletely observed or reported, but it is also constrained by requiring a sufficiently long time series and assumes the effort to detect whale deaths remains constant.

3.3. *Risk reduction estimates*

Risk reduction probability calculations have been used to estimate strike rates and to assess the effectiveness of various strike reduction measures. For example, based on strike-rate analysis for large baleen whales, including right whales, on global and regional bases, Vanderlaan et al. [25] reported a 3- to 4-fold increase in the number of reported strikes worldwide from the early 1970s to the early 2000s and estimated a 50% chance of 14 or more annual vessel-strike reports worldwide between 1999 and 2002. Noting that obtaining risk reduction probabilities rely on the validity of several assumptions – including a vessel strike can occur at any time or place along a vessel route, the probability of a strike is small, and vessel strikes are independent events – Vanderlaan et al. [25] concluded that where sufficient data are available, a modeling tool they developed can be used to predict the expected change in vessel strikes stemming from a given conservation action in various geographic locations. Here, again, long time series (i.e., years or decades) before and after the implementation of a conservation initiative are needed to adequately evaluate the action [25,73].

Estimates of risk reduction have also been applied to measures adopted by the IMO. For example, the efficacy of the Roseway Basin ATBA was initially uncertain because it was based on recommendatory actions. Indeed, adherence with its provisions was lowest in the first two weeks and ranged from 57% to 87%, but some learning about the ABTA may have been involved because in the course of the first year compliance had stabilized at ~71% [17]. The corresponding risk reduction was estimated at 82% and, thus, Vanderlaan and Taggart [17] concluded that an IMO-adopted ATBA, although recommendatory, was an effective means to protect endangered whales.

In a comparison of the merits of vessel re-routing versus speed restrictions in the Bay of Fundy, Vanderlaan et al. [16] reported a 62% risk reduction versus 52% risk reduction when using vessel re-routing and speed restrictions, respectively (Fig. 2). Thus, although there is still considerable risk of lethal vessel strikes within the Bay, reductions in risk have been achieved with minimal effects on maritime operations.

With regard to modification of the Boston TSS, Merrick [44] provided estimates of vessel strike reduction of 58% for right whales and an 81% reduction for other large whale species in the area (i.e., fin, humpback (*Megaptera novaeanglia*), and minke (*B. acutorostrata*) whales) if the TSS was amended as proposed. However, post-implementation analysis of this measure has not been conducted. Canada's proposal to the IMO to amend the Bay of Fundy TSS provided an estimated 80% reduction in the relative probability of a vessel encountering a right whale [16]. Further analyses (which included a vessel speed term and an algorithm that 'moved' those vessels transiting the original lanes into the amended lanes) indicated an estimated average reduction in relative risk of a lethal vessel strike of 90% relative to the TSS's original configuration (Fig. 2(b)). In considering the entire Bay of Fundy, amending the TSS reduced the risk of a lethal vessel strike by approximately 62% [16], and resulted in estimated decreases in risk of lethal strikes by 28% to minke, 27% to fin, 17% to sei (*B. borealis*), and 9% to humpback whales.

4. Conclusions

Actions are being taken worldwide to reduce the threat of vessel strikes of large whales, some via endorsement by the IMO. To date, the IMO has deliberated on a total of 10 actions to reduce the threat of ship strikes to large whales in three regions. Although the processes used by the IMO may be confusing to some, we found that proposals that provided strong needs statements, were accompanied by relevant documentation, contained an assessment of impact to maritime industries, and included robust risk reduction analysis were likely to be successful. Only IMO members can submit proposals. Consideration should be given prior to submission to monitoring of the measures, and to the necessary domestic coastal state regulations, legislation, or other mechanisms that might be instrumental in implementing the measures.

Specific actions described here for waters off Canada and the USA and those in the Mediterranean share these features: substantial information existed on whale occurrence and distribution, thereby facilitating the establishment of specific routing measures relative to whale occurrence; and vessel transit patterns and volume were relatively easily obtained (and therefore, compliance rates and impacts to industry could be assessed). Analogous efforts in other locations (e.g., the open ocean) may face difficulties if biological information and technological capabilities for tracking vessels are limited.

The technology, data, and analytical tools exist for assessing the relative effectiveness of IMO-endorsed measures. Vessel compliance with IMO-endorsed measures, even for those that are recommendatory, is generally high. The success of these measures is likely enhanced by the existence of constructive links between authorities implementing the measures and the affected maritime shipping entities, bearing in mind that main concerns for these entities, and that of the IMO, are safety and security at sea. The relative success of IMO-adopted navigational measures speak to the influence and international reach of the IMO, and make it a powerful forum for coastal states to implement whale conservation measures and for addressing a range of marine environmental issues, especially where shipping has been identified as a threat to the ocean environment.

Acknowledgements

We are deeply indebted to our coauthor, the late Lindy Johnson, whose life and career were the definition of an unwavering commitment to marine conservation. Much of what is presented above would not have been possible without her guiding hand. For their support in finding vessel-strike solutions we thank G. Detweiler, E. LaRue, and M. Solosi at the USCG in the USA; I. Martín, S. Rodriguez, M. Nogueira, J. Pantoja and F. Ramos in Spain; R. Tuner at Transport Canada; and M. Palomares at the IMO. Research conducted in the Mediterranean was funded by LIFE Nature Projects numbers LIFE02NAT/E8610 and LIFE07NAT/E00732. Critical reviews by P. Openheimer, E. LaRue and anonymous referees helped improve this manuscript.

Appendix A

A listing of vessel navigation definitions and instruments available to International Maritime Organization (IMO) as reflected in the annual IMO publication entitled: Ships' Routeing.

Area To Be Avoided (ATBA): a routing measure comprising an area where navigation is particularly hazardous or exceptionally important to avoid casualties and should be avoided by all, or certain classes, of vessels.

Deep-water route: a route which has been accurately surveyed for clearance of sea bottom and submerged obstacles as indicated on nautical charts.

Fairway: a lane or corridor in which no artificial island or structure, temporary or permanent, will be permitted so that vessels using ports will have unobstructed approaches.

Inshore traffic zone: a routing measure comprising a designated area between the landward boundary of a traffic separation scheme and the adjacent coast.

Mandatory Ship Reporting System: systems used to provide, gather, or exchange information through radio reports or other means of communication. The information is used to provide data for many purposes including, but not limited to, navigation safety, environmental protection, vessel traffic services, search and rescue, weather forecasting, and prevention of marine pollution.

No anchoring area: a routing measure identifying an area where anchoring is hazardous or could result in unacceptable damage to the marine environment. Anchoring in a no anchoring area should be avoided by all vessels or certain classes of vessels, except in case of immediate danger to the vessel or persons on board.

Particularly Sensitive Sea Area (PSSA): an area that needs special protection because of its significance for recognized ecological, socio-economic, or scientific reasons and which may be vulnerable to damage by international maritime activities. The criteria for the identification of a PSSA and the criteria for the designation of Special Areas are not mutually exclusive. In many cases a Particularly Sensitive Sea Area may be identified within a Special Area and vice versa.

Precautionary area: a routing measure comprising an area within defined limits where vessels must navigate with particular caution and within which the direction of traffic flow may be recommended.

Recommended route: a route of undefined width, for the convenience of vessels in transit, which is often marked by centerline buoys.

Recommended track: a route which has been specially examined to ensure so far as possible that it is free of dangers and along which vessels are advised to navigate.

Regulated Navigation Area: an area for which specific regulations for vessels navigating within the area have been established.

Roundabout: a routing measure comprising a separation point or circular separation zone and a circular traffic lane. Traffic within the roundabout is separated by moving in a counterclockwise direction around the separation point or zone.

Separation Zone or separation line: a zone or line separating the traffic lanes in which vessels are proceeding in opposite or nearly opposite directions; or from the adjacent sea area; or separating traffic lanes designated for particular classes of vessels proceeding in the same direction.

Traffic lane: an area in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.

Traffic Separation Scheme (TSS): a routing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes. The traffic-lanes (or clearways) indicate the direction of the ships in that zone; ships navigating within a TSS all sail in the same direction or they cross the lane in an angle as close to 90 degrees as possible. TSS's are used to regulate the traffic at busy, confined waterways or around capes, and usually consist of at least one traffic-lane in each main-direction, turning-points, deep-water lanes and separation zones between the main traffic lanes.

Two-way route: a route in which two-way traffic is established, aimed at providing safe passage of ships through waters where navigation is difficult or dangerous.

Vessel routing system: any system of one or more routes or routing measures aimed at reducing the risk of casualties; it includes traffic separation schemes, two-way routes, recommended tracks, areas to be avoided, no anchoring areas, inshore traffic zones, roundabouts, precautionary areas, and deep-water routes.

References

[1] Hazel J, Gyuris E. Vessel-related mortality of sea turtles in Queensland, Australia. Wildlife Res 2006;33(2):149–54.

[2] Hazel J, Lawler IR, Marsh H, Robson S. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. Endangered Species Res 2007;3: 105–113.

[3] Greenland JA, Limpus CJ Marine wildlife stranding and mortality database: cetaceans and pinnipeds. In *Conservation technical and data report*, Environmental Protection Agency: Freshwater and Marine Sciences Unit, State of Queensland, 2005.

[4] Lightsey JD, Rommel SA, Costidis AM, Pitchford TD. Methods used during gross necropsy to determine watercraft-related mortality in the Florida manatee (*Trichechus manatus latirostris*). J Zoo Wildlife Med 2006;37(3): 262–275.

[5] Van Waerebeek K, Baker AN, Felix F, Gedamke J, Inigeuz M, Sanino GP, et al. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere; building a standardized database. Paper to the IWC Scientific Committee. St Kitts and Nevis, West Indies, SC/58/BC6, 2006.

[6] Clapham PJ, Young SB, Brownell Jr. RL. Baleen whales: conservation issues and the status of the most endangered populations. Mammal Rev 1999;29(1):35–60.

[7] Laist DW, Knowlton AR, Mead JG, Collet AS, Podesta M. Collisions between ships and whales. Mar Mammal Sci 2001;17(1):35–75.

[8] Van Waerebeek K, Leaper R. Second Report of the IWC Vessel Strike Data Standardisation Working Group. Paper to the IWC Scientific Committee. Santiago, Chile, SC/60/BC5, 2008.

[9] Moore MJ, Knowlton AR, Kraus SD, Mclellan WA, Morphometry Bonde RK. gross morphology and available histopathology in North Atlantic right whale (*Eubalaena glacialis*) mortalities (1970–2002). J Cetac Res Manage 2004;6(3):199–214.

[10] Glass AH, Cole TVN, Garron M. Mortality and serious injury determinations for baleen whale stocks along the United States and Canadian Eastern Seaboards, 2004–2008., 27, NMFS, 2010.

[11] Kraus SD, Brown MW, Caswell H, Clark CW, Fujiwara M, Hamilton PK, et al. North Atlantic right whales in crisis. Science 2005;309:561–2.

[12] Fujiwara M, Caswell H. Demography of the endangered North Atlantic right whale. Nature 2001;414:537–41.

[13] Campbell-Malone R, Barco SG, Daoust P-Y, Knowlton AR, McLellan WA, Rotstein DS, et al. Gross and histologic evidence of sharp and blunt trauma in North Atlantic right whales (*Eubalaena glacialis*) killed by vessels. J Zoo Wildlife Med 2008;39(1):37–55.

[14] Tejedor A, Sagarminaga R, Cañadas A, de Stephanis R, Pantoja J. Modifications of maritime traffic off Southern Spain. Document presented to the Scientific Committee of the International Whaling Commission. SC/59/BC3, 12007.

[15] Bettridge S, Silber GK. Update on the United States' actions to reduce the threat of ship collisions with large whales. Paper to the International Whaling Commission's Conservation Committee's Working Group on Ship Strikes, Santiago, Chile, 2008.

[16] Vanderlaan ASM, Taggart CT, Serdynska AR, Kenney RD, Brown MW. Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endangered Species Res 2008;4(3) 283-283.

[17] Vanderlaan ASM, Taggart CT. Efficacy of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. Conserv Biol 2009;23(6):1467–74.

[18] National Marine Fisheries Service. Final Rule: speed restrictions to reduce the threat of ship collisions with North Atlantic right whales. U.S. Department of Commerce. 73 FR 60173, 2008.

[19] National Park Service. Glacier Bay National Park: vessel management plan regulations. U.S. Department of the Interior. 71 FR 230, 2006.

[20] Gende S, Hendrix N, Harris K, Eichenlaub B, Nielsen J, Pyare S. A bayesian approach for understanding the role of ship speed in whale-ship encounters. Ecological Applications 2011;21:2233–40.

[21] SOLAS. International Convention on Safety of Life at Sea. Chapter V: Safety of Navigation, Merchant Shipping Regulations. 1473, 2002.

[22] UNCLOS. United Nations Convention on the Law of the Sea. 1982.

[23] International Union of Conservation for Nature. *Red List of Threatened Species, Version 2010.4*. 2010; Available from: www.iucnredlist.org.

[24] Brown MW, Fenton D, Smedbol K, Merriman C, Robichaud-LeBlanc K, Conway J. Recovery strategy for the North Atlantic right whale (*Eubalaena glacialis*) in Atlantic Canadian waters. In *Species at Risk Act Recovery Strategy Series*, Department of Fisheries and Oceans, Canada, 2009.

[25] Vanderlaan ASM, Corbett JJ, Green SL, Callahan JA, Wang C, Kenney RD, et al. Probability and mitigation of vessel encounters with North Atlantic right whales. Endangered Species Res 2009;6:273–85.

[26] Nelson M, Garron M, Merrick RL, Pace III RM, Cole TVN. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and adjacent Canadian Maritimes, 2001–2005. Northeast Fisheries Science Center Reference Document 07–05, U.S. Department of Commerce, NOAA, 2007.

[27] Jensen AS, Silber GK. Large whale ship strike database. Technical Memorandum NMFS-OPR-25, U.S. Department of Commerce, NOAA, 2003.

[28] Vanderlaan ASM, Taggart CT. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Mar Mammal Sci 2007;23(1):144–56.

[29] Silber GK, Slutsky J, Bettridge S. Hydrodynamics of a ship/whale collision. J Exp Mar Biol Ecol 2010;391(1–2):1–9.

[30] Terhune JM, Verboom WC. Right whales and ship noises. Mar Mammal Sci 1999;15(1):256–8.

[31] Nowacek DP, Johnson MP, Tyack PL. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proc R Soc London 2004;271:227–31.

[32] Notarbartolo Di Sciara G, Birkun A. Conserving whales, dolphins and porpoises in the Mediterranean and Black Seas. In *ACCOBAMS Status Report 2010*, Monaco, 2010.

[33] Cagnolaro L, Notarbartolo Di Sciara G. Attivita di ricerca sui cetacei e loro status di conservazione in Italia. (Research Activities and Conservation Status of Cetaceans in Italy). Bollettino Del Musei E Degli Istituti Biologici Dell' Universita Di Genova; 1992 56–57: 53-85.

[34] Panigada S, Pesante G, Zanardelli M, Capoulade F, Gannier A, Weinrich MT. Mediterranean fin whales at risk from fatal ship strikes. Mar Pollut Bull 2006;52:1287–98.

[35] Azzellino A, Gaspari S, Airoldi S, Nani B. Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. Deep Sea Res Part I 2008;55(3):296–323.

[36] Silber GK, Bettridge S, Cottingham D. Report of a Workshop to Identify and Assess Technologies to Reduce Ship Strikes of Large Whales. Technical Memorandum NMFS-OPR-42, U.S. Department of Commerce, NOAA, 2009.

[37] United States Government. Ship strikes of endangered northern right whales. Report to the Maritime Safety Committee of the International Maritime Organization. 1997.

[38] Johnson LS. Coastal State Regulation of International Shipping. Dobbs Ferry, NY: Oceana: Publications, Inc; 2004.

[39] United States Government. Ship Reporting Systems for Eastern Coast of the United States. Proposal submitted to the IMO's Sub-Committee on Safety of Navigation. 1998.

[40] Anonymous. President's statement on protecting the northern right whale, April 23. 34, Weekly Compilation of Presidential Documents, 1998.

[41] Luster JP. The international maritime organization's new mandatory ship reporting system for the northern right whale's critical habitat: a legitimate approach to strengthening the Endangered Species Act? Nav L Rev 1999;46:153–69.

[42] Detweiler GH, Silber GK, Bettridge S. Protecting the North Atlantic right whale. Proc Mar Saf Secur Counc 2007;64(2):48–51.

[43] Ward-Geiger LI, Silber GK, Baumstark RD, Pulfer TL. Characterization of ship traffic in right whale critical habitat. Coast Manage 2005;33:263–78.

[44] Merrick RL. Seasonal management areas to reduce ship strikes of northern right whales in the Gulf of Maine. Northeast Fisheries Science Center Reference Document 05–19, 26, U.S. Department of Commerce, NOAA, 2005.

[45] Merrick RL, Cole TVN. Evaluation of northern right whale ship strike reduction measures in the Great South Channel of Massachusetts. Technical Memorandum NMFS-NE-202, U.S. Department of Commerce, NOAA, 2007.

[46] International Maritime Organization. Report of the Maritime Safety Committee on its Sixty-ninth Session. MSC 69/22, 1998.

[47] U.S. Coast Guard. Mandatory Ship Reporting Systems. U.S. Department of Homeland Security. 66 FR 58066, 2001.

[48] International Maritime Organization. Report of the Maritime Safety Committee on its Forty-sixth Session. 46, 1982.

[49] Brown MW, Kenney RD, Taggart CT, Vanderlaan ASM, Owen J, Beaudin Ring J, et al. Measures to Reduce the Potential for Interactions between the Endangered North Atlantic Right Whale and Large Vessels in the Waters of Atlantic Canada. Halifax, Nova Scotia: Regional Canadian Marine Advisory Council; 2001.

[50] Brown MW, Kenney RD, Taggart CT, Vanderlaan ASM, Owen J, Beaudin Ring J, et al. Measures to Reduce the Potential for Interactions between the Endangered North Atlantic Right Whale and Large Vessels in the Waters of Atlantic Canada. Ottawa, Canada: National Canadian Marine Advisory Council; 2001.

[51] International Maritime Organization. Report of the Sub-Committee on Safety of Navigation on its Forty-eighth Session. NAV 48/19, 2002.

[52] International Maritime Organization. Report of the Maritime Safety Committee on its Seventy-sixth Session. MSC 76/23, 2002.

[53] Cañadas A, Sagarminaga R, De Stephanis R, Urquiola E, Hammond PS. Habitat selection modeling as a conservation tool: proposals for marine protected areas for cetaceans in southern Spanish waters. Aquat Conserv 2005;15: 495–521.

[54] Reeves R, Notarbartolo Di Sciara G. The Status and Distribution of Cetaceans in the Black Sea and Mediterranean Sea. Malaga, Spain: International Union for Conservation of Nature Centre for Mediterranean Cooperation; 2006.

[55] International Maritime Organization. Amendment to the Traffic Separation Scheme off Cabo de Gata. NAV 51/3/7, 2005.

[56] International Maritime Organization. Report of the Maritime Safety Committee on its Eighty-first Session. MSC 81/10, 2005.

[57] International Maritime Organization. New and Amended Existing Traffic Separation Schemes. COLREG 2/Circ. 58, 2006.

[58] Tejedor Arceredillo A, Sagarminaga R, Stephanis RD, Canadas A, Lago A. Management of MPAs: Options and challenges for the maritime transport sector. Spanish case studies. In *Workshop at the 21st Annual Meeting of the*

ECS: Selection Criteria for Marine Protected Areas for Cetaceans, 48, 93–98 ECS Special Publication Series, San Sebastian, Spain, 2008.
[59] De Stephanis R, Cornulier T, Verborgh P, Sierra JS, Gimeno NP, Guinet C. Summer spatial distribution of cetaceans in the Strait of Gibraltar in relation to the oceanographic context. Mar Ecol Prog Ser 2008;353:275–88.
[60] International Maritime Organization. Routing of ships; precautionary areas on the eastern side of and off the Moroccan port of Tangiers-Med, and division of the southern inshore traffic zone in the Strait of Gibraltar traffic separation scheme. NAV 52/3/2, 2006.
[61] International Maritime Organization. Report of the Maritime Safety Committee on its Eighty-second Session. MSC 82/11, 2006.
[62] International Maritime Organization. Report of the Sub-Committee on Safety of Navigation on its Fifty-fourth Session. NAV 54/25, 2008.
[63] United States Government. Amendment of the Traffic Separation Scheme in the Approach to Boston, Massachusetts. Proposal submitted to the International Maritime Organization's Sub-Committee on Safety of Navigation. 2006.
[64] Brown MR, Corkeron PJ, Hale PT, Schultz KW, Bryden MM. Evidence for a sex-segregated migration in the humpback whale (*Megaptera novaeangliae*). Proc R Soc London B 1995;259:229–34.
[65] Brown MW, Taggart CT, Vanderlaan ASM, Serdynska AR. Proposal for an area to be avoided on Roseway Basin, south of Nova Scotia. In National Conference: Standing Committee on Navigation and Operations, Canadian Marine Advisory Council, Ottawa, Canada, 2006.
[66] International Maritime Organization. Routing measures other than traffic separation schemes. SN/Circ 2007;263.
[67] International Maritime Organization. Amendment to the Traffic Separation Scheme in the Approach to Boston, Massachusetts. NAV 54/3, 2008.
[68] International Maritime Organization. Report of the Maritime Safety Committee on its Eighty-fifth Session. MSC 85/11, 2008.
[69] U.S. Coast Guard. Port access route study of potential vessel routing measures to reduce vessel strikes of North Atlantic right whales. U.S. Department of Homeland Security. 72 FR 64968, 2007.
[70] United States Government. Area to be Avoided in the Great South Channel. Proposal submitted to the IMO's Sub-Committee on Safety of Navigation. 2008.
[71] International Maritime Organization. Report of the Marine Environment Protection Committee on its Fifty-eighth Session. MEPC 58/23/18, 2008.
[72] International Maritime Organization. Measures for minimizing the risks of collisions with cetaceans. MEPC 59/18, 2009.
[73] Silber GK, Bettridge S. Report of a Workshop on Assessing the Effectivness of the Right Whale Ship Strike Reducton Rule. U.S. Department of Commerce, Silver Spring, MD, 2009.
[74] Knowlton AR, Brown MW. Running the Gauntlet: right whales and vessel strikes. In: Kraus SD, Rolland RM, editors. The Urban Whale: North Atlantic Right Whales at the Crossroads. Cambridge, Mass.: Harvard University Press; 2007. p. 409–35.
[75] Corbett JJ, Koehler HW. Updated emissions from ocean shipping. J Geophys Res 2003;108(D20):4650–66.
[76] Corbett J. Marine transportation and energy use. In: Cleveland CJ, editor. Encyclopedia of Energy, 3. San Diego, CA: Elsevier Science; 2004. p. 745–8.
[77] Wang C, Corbett JJ, Firestone J. Improving spatial representation of global ship emissions inventories. Environ Sci Technol 2008;42:193–9.
[78] Corbett JJ, Winebrake JJ, Green EH, Kasibhatla P, Eyring V, Lauer A. Mortality from ship emissions: a global assessment. Environm Sci Technol 2007;41: 8512–8518.
[79] International Maritime Organization. Report of the Marine Safety Committee on its Eighty-fourth Session. MSC 263/84, 2008.
[80] International Maritime Organization. Guidelines for the installation of a shipborne Automative Identification System (AIS). NAV/Circ 2003;227.
[81] Harati-Mokhtarie A, Wall A, Brooks P, Wang J. Automatic identificantion system (AIS): reliability and human error implications. J Navig 2007;60(3): 373–389.
[82] Aarsæther KG, Moan T. Estimating navigation patterns from AIS. J Navig 2009;62(4):587–607.
[83] Hatch L, Clark C, Merrick R, Van Parijs S, Ponirakis D, Schwehr K, et al. Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Environ Manage 2008;42(5):735–52.
[84] Silber GK, Bettridge S. Vessel operations in right whale protection areas in 2009. Technical Memorandum NMFS-OPR-44, U.S. Department of Commerce, NOAA 2010.
[85] Pace III RM. Frequency of Whale and Vessel Collisions on the U.S. Eastern Seaboard: Ten Years Prior and Two Years Post Ship Strike Rule. Northeast Fisheries Science Center; 2011.