

Using passive acoustic monitoring from gliders for near real-time detection of North Atlantic right whales (*Eubalaena glacialis*) and management of the Laurentian Channel Dynamic Shipping Zones

Prepared for
the Innovation Centre
of Transport Canada

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Date: August 16, 2021

NOTICES

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Acknowledgements:

This study would not have been possible without the work and collaboration of many organizations. The study was funded by Transport Canada's Innovation Centre (TC/IC) and supported by Laurence Lecavalier, Denis Tran and Véronique Nolet at the IC. The glider was leased from Teledyne Webb Research (TWR), and piloted by TWR pilots. Thank you to Chris Decollibus, Ben Allsup, Joe Gradone, and Clara Hulburt at TWR for collaborating on the project. The DMON hydrophone and real-time acoustic software and automated dissemination of real-time detections to partners were provided through collaboration by Dr. Mark Baumgartner at Woods Hole Oceanographic Institution. Dr. Baumgartner generously volunteered his time to provide web support for this mission for which we are exceptionally grateful. The CEOTR glider team at Dalhousie University (Adam Comeau, Jude Vander Meer) expertly prepared, deployed and recovered the glider. Thank you to the vessel captains in Rivière-au-Renard who supported deployment and recovery. Finally, thank you to Hansen Johnson at Dalhousie University who operates WhaleMap, and conserve.IO who operate the Whale Alert App, for supporting the distribution of real-time acoustic detections from the glider on their respective platforms.

Un sommaire en français se trouve avant la table des matières.



1. Transport Canada Publication No. TP 15579		2. Project No. -		3. Recipient's Catalogue No. -	
4. Title and Subtitle Using passive acoustic monitoring from gliders for near real-time detection and dynamic management of North Atlantic right whales (<i>Eubalaena glacialis</i>) in the Laurentian Channel Dynamic Shipping Zones				5. Publication Date August 16th, 2021	
				6. Performing Organization Document No. -	
7. Author(s) Kimberley T A Davies				8. Transport Canada File No. -	
9. Performing Organization Name and Address University of New Brunswick PO Box 4400 Fredericton, New Brunswick E3B 5A3				10. PWGSC File No. XLV-0-43012	
				11. PWGSC or Transport Canada Contract No. T8009-200049/001/XLV	
12. Sponsoring Agency Name and Address Innovation Centre (IC) Place de Ville, Tower C 330 Sparks Street, 18th Floor Ottawa, Ontario K1A 0N5				13. Type of Publication and Period Covered Final	
				14. Project Officer Véronique Nolet	
15. Supplementary Notes (Funding programs, titles of related publications, etc.) This report was funded as part of the Marine RD&D Program					
16. Abstract <p>The goal of this project was to use right whale detections made by the glider to trigger dynamic vessel management in the traffic separation scheme within Dynamic Shipping Zone C (DSZ C). A profiling glider equipped with a hydrophone system was deployed for an 89-day mission from August 16th through November 10th, 2020. The glider reported daily detections of five species of baleen whales that were validated by a trained human analyst before being distributed to Transport Canada. The glider detected right whales in DSZ C on seven survey days. In response to the glider detections, the speed limit was in place in DSZ C for 32.5 days, or 47.8 % of the survey period. On October 23rd, 2020, the glider departed DSZ C and was recovered near the west shore of Cape Breton on 12 November. The false detection rate for right whale detections at the daily scale was 0%, and the false negative rate for this species at the daily scale was 12.5%, which is within normal operating parameters for this system. The mission objectives were successfully fulfilled.</p>					
17. Key Words North Atlantic right whale, glider, dynamic management, whale conservation, Dynamic Shipping Zones, Gulf of St. Lawrence			18. Distribution Statement Digital Copy		
19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) -	22. No. of Pages 22	23. Price -	



1. N° de la publication de Transports Canada TP 15579	2. N° de l'étude -	3. N° de catalogue du destinataire -		
4. Titre et sous-titre Utilisation de la surveillance acoustique passive à partir de planeurs pour la détection en temps quasi réel et la gestion dynamique des baleines noires de l'Atlantique Nord (<i>Eubalaena glacialis</i>) dans les zones dynamiques de navigation du chenal Laurentien		5. Date de la publication 16 août 2021		
		6. N° de document de l'organisme exécutant -		
7. Auteur(s) Kimberley T. A. Davies		8. N° de dossier - Transports Canada -		
9. Nom et adresse de l'organisme exécutant Université du Nouveau-Brunswick Boîte Postale 4400 Fredericton, Nouveau-Brunswick E3B 5A3		10. N° de dossier - TPSGC XLV-0-43012		
		11. N° de contrat - TPSGC ou Transports Canada T8009-200049/001/XLV		
12. Nom et adresse de l'organisme parrain Centre d'innovation (IC) Place de Ville, tour C 330, rue Sparks, 18e étage Ottawa (Ontario) K1A 0N5		13. Genre de publication et période visée Final		
		14. Agent de projet Véronique Nolet		
15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.) Ce rapport a été financé dans le cadre du programme de RDD maritime.				
16. Résumé <p>Le but de ce projet était d'utiliser les détections de baleines noires effectuées par le planeur pour déclencher une gestion dynamique des navires dans le dispositif de séparation du trafic au sein de la zone de transport maritime dynamique C (ZTMD C). Un planeur de profilage équipé d'un système d'hydrophone a été déployé pour une mission de 89 jours, du 16 août au 10 novembre 2020. Le planeur a signalé des détections quotidiennes de cinq espèces de baleines à fanons, qui ont été validées par un analyste humain formé avant d'être communiquées à Transports Canada. Le planeur a détecté des baleines noires dans la ZTMD C pendant sept jours de relevé. En réponse aux détections du planeur, une limitation de vitesse a été mise en place dans la ZTMD C pendant 32,5 jours, soit 47,8 % de la période de relevé. Le 23 octobre 2020, le planeur a quitté la ZTMD C et a été récupéré près de la côte ouest du cap Breton le 12 novembre. Le taux de fausses détections de baleines noires à l'échelle journalière était de 0 %, et le taux de faux négatifs pour cette espèce à l'échelle journalière était de 12,5 %, ce qui est conforme aux paramètres d'exploitation normaux de ce système. Les objectifs de la mission ont été atteints avec succès</p>				
17. Mots clés Baleine noire de l'Atlantique Nord, planeur, gestion dynamique, conservation des baleines, couloirs de navigation dynamiques, golfe du Saint-Laurent		18. Diffusion Copie numérique		
19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) -	22. Nombre de pages 22	23. Prix -

EXECUTIVE SUMMARY

Several right whale-vessel strikes have occurred in the Gulf of St. Lawrence since 2017. In response, Transport Canada, in collaboration with industry and academia, initiated a series of management measures that includes dynamic management of vessel traffic in the shipping lanes in the Laurentian Channel north and south of Anticosti Island. Prior to 2019, slowdowns to reduce the risk of vessel strike in the Dynamic Shipping Zones (DSZs) were solely triggered by real-time detections of right whales made visually. Visual detection has key limitations, including that it cannot be done in poor weather conditions (high wind, storms), or at night. This project was initiated in response to a request from Transport Canada to adopt autonomous mobile underwater gliders as an additional tool for monitoring North Atlantic right whales (*Eubalaena glacialis*, hereafter right whales) acoustically in real-time. Beginning in 2020, real-time detections that trigger slowdowns have been collected both visually (from airplanes and an aerial drone) and acoustically using gliders.

The primary goal of this project was to use right whale detections made by the glider to trigger dynamic vessel management in the traffic separation scheme within Dynamic Shipping Zone C (DSZ C). After completing the primary goal, the secondary goal was to transit the glider through the Cabot Strait region to test whether it was feasible to fly the glider in a well-controlled manner in this region. The performance of the glider and real-time system during the deployment were evaluated.

A profiling electric glider equipped with a hydrophone system capable of detecting and classifying right whale upcalls in real-time was deployed for a 89-day mission in the Laurentian Channel from 16 August through 10 November, 2020. The glider reported daily detections of five species of baleen whales, including right whales, that were validated by a trained human analyst before being distributed to Transport Canada for any necessary management actions and for publication to the publicly available WhaleMap website. During the first 68 days of the mission, the mobile glider made 12 transits of an along-channel transect located between the inbound and outbound shipping lanes of DSZ C. Course deviations due to ocean currents were minimal (nominally < 1 nautical mile), and the glider was able to safely navigate between the shipping lanes. The glider made definite right whale detections in DSZ C on seven survey days. A 10-knot speed limit in DSZ C was implemented within 24 hours of a real-time detection and remained in effect for 15 consecutive days unless temporarily lifted due to poor weather. In response to the glider detections, the speed limit was in place in DSZ C for 32.5 days (780 hours), or 47.8 % of the survey period.

On 23 October 2020, the glider departed DSZ C to navigate between the shipping lanes from DSZ C, through DSZ E and along the Cabot Strait. When it reached the approximate mid-point of DSZ E, it encountered a consistent northward current that pushed it into the inbound shipping lane. For the safety of the glider, the glider was moved into the buffer zone to the north of the inbound shipping lane, where it remained until it entered the Cabot Strait. There were no further navigational issues within the Cabot Strait and, based on the information collected, it is not foreseen that there would be obstacles to prevent future glider surveys of the region. During 22 October through 27 October an interruption occurred in the Iridium satellite network and real-time data communication was temporarily disrupted during this time. The glider was later recovered near the west shore of Cape Breton on 12 November.

After the glider was recovered, the recorded audio data were analyzed for right whale calls and performance statistics of the real-time data were generated. The false detection rate for right whale

detections at the daily scale was 0%, and the false negative rate for this species at the daily scale was 12.5%, which is within normal operating parameters for this system. The mission objectives were successfully fulfilled. The experiences of the research team conducting this and many other glider missions in the Gulf of St. Lawrence suggest gliders can be deployed autonomously and without a support vessel to survey almost anywhere in the region except in narrow passages with strong currents. Extra precautions such as a support vessel would be prudent in narrow passages such as the Jacques Cartier Passage, Baie des Chaleurs and Strait of Belle Isle.

SOMMAIRE

Plusieurs collisions entre des baleines noires et des navires ont eu lieu dans le golfe du Saint-Laurent depuis 2017. En réponse, Transports Canada, en collaboration avec l'industrie et le milieu universitaire, a mis en œuvre une série de mesures de gestion comprenant la gestion dynamique du trafic maritime dans les voies de navigation du chenal Laurentien au nord et au sud de l'île d'Anticosti. Avant 2019, les ralentissements visant à réduire le risque de collision avec les navires dans les zones de transport maritime dynamiques (ZTMD) étaient uniquement déclenchés par des détections visuelles en temps réel de baleines noires. La détection visuelle présente des limites importantes, notamment le fait qu'elle ne peut pas être effectuée dans de mauvaises conditions météorologiques (vent fort, tempêtes) ou la nuit. Ce projet a été lancé en réponse à une demande de Transports Canada visant à adopter des planeurs sous-marins mobiles autonomes comme outil supplémentaire pour la surveillance acoustique en temps réel des baleines noires de l'Atlantique Nord (*Eubalaena glacialis*, dénommées « baleines noires » ciaprès). Depuis 2020, les détections en temps réel qui déclenchent des ralentissements sont recueillies à la fois visuellement (à partir d'avions et d'un drone aérien) et acoustiquement à l'aide de planeurs.

Le but principal de ce projet était d'utiliser les détections de baleines noires effectuées par le planeur pour déclencher une gestion dynamique des navires dans le dispositif de séparation du trafic au sein de la zone de transport maritime dynamique C (ZTMD C). Après avoir atteint le but principal, le but secondaire était de faire passer le planeur par la région du détroit de Cabot afin de vérifier s'il était possible de le faire voler de manière bien contrôlée dans cette région. Les performances du planeur et du système en temps réel pendant le déploiement ont été évaluées. Un planeur électrique de profilage équipé d'un système d'hydrophone capable de détecter et de classer les cris d'appel de baleines noires en temps réel a été déployé pour une mission de 89 jours dans le chenal Laurentien, du 16 août au 10 novembre 2020. Le planeur a signalé des détections quotidiennes de cinq espèces de baleines à fanons, dont des baleines noires, qui ont été validées par un analyste humain formé avant d'être communiquées à Transports Canada pour qu'il appuie toute mesure de gestion nécessaire et qu'il publie les données sur le site Web WhaleMap, qui est accessible au public. Au cours des 68 premiers jours de la mission, le planeur mobile a effectué 12 passages sur un transect le long du chenal situé entre les voies de navigation entrantes et sortantes de la ZTMD C. Les déviations de trajectoire dues aux courants océaniques ont été minimales (nominalement < 1 mille nautique), et le planeur a pu naviguer en toute sécurité entre les voies de navigation. Le planeur a effectué des détections confirmées de baleines noires dans la ZTMD C au cours de sept jours de relevé. Une limitation de vitesse à 10 nœuds dans la ZTMD C a été mise en œuvre dans les 24 heures suivant une détection en temps réel et est restée en vigueur pendant 15 jours consécutifs, sauf durant les jours de mauvaises conditions météorologiques, où la mesure a été temporairement levée. En réponse aux détections du planeur, la limitation de vitesse a été mise en place dans la ZTMD C pendant 32,5 jours (780 heures), soit 47,8 % de la période de relevé.

Le 23 octobre 2020, le planeur a quitté la ZTMD C pour se déplacer entre les voies de navigation de la ZTMD C, à travers la ZTMD E et le long du détroit de Cabot. Lorsqu'il a atteint approximativement le milieu de la ZTMD E, il a rencontré un courant constant vers le nord qui l'a poussé dans la voie de navigation entrante. Pour sa sécurité, le planeur a été dirigé vers la zone tampon au nord de la voie de navigation entrante, où il est resté jusqu'à ce qu'il entre dans le détroit de Cabot. Il n'y a pas eu d'autres problèmes de navigation dans le détroit de Cabot et, sur la base des renseignements recueillis, il n'est

pas prévu qu'il y ait des obstacles qui empêchent la réalisation de futurs relevés par des planeurs dans la région. Du 22 au 27 octobre, une interruption s'est produite dans le réseau de satellites Iridium et la communication de données en temps réel a été temporairement interrompue pendant cette période. Le planeur a ensuite été récupéré près de la côte ouest du cap Breton le 12 novembre. Une fois le planeur récupéré, les données audio enregistrées ont été analysées pour détecter des appels de baleines noires et des statistiques de performance des données en temps réel ont été générées. Le taux de fausses détections de baleines noires à l'échelle journalière était de 0 %, et le taux de faux négatifs pour cette espèce à l'échelle journalière était de 12,5 %, ce qui est conforme aux paramètres d'exploitation normaux de ce système. Les objectifs de la mission ont été atteints avec succès. L'expérience de l'équipe de recherche qui a mené cette mission et de nombreuses autres dans le golfe du Saint-Laurent montre que des planeurs peuvent être déployés de façon autonome et sans navire de soutien pour effectuer des relevés presque partout dans la région, sauf dans les passages étroits où l'on observe de forts courants. Des précautions supplémentaires, telles qu'un navire de soutien, sont recommandées dans les passages étroits tels que le détroit de Jacques-Cartier, la baie des Chaleurs et le détroit de Belle-Isle.

CONTENTS

1.0 Introduction	1
2.0 Methodology	2
2.1 Observational Technology.....	2
2.2 Mission Plan	3
2.3 Data Analysis	5
3.0 Results.....	5
3.1 Glider Flight Characteristics	5
3.2 North Atlantic right whale detections.....	7
4.0 Conclusions and Recommendations.....	9
4.1 System Performance	9
4.2 Glider Communications.....	10
4.3 Flight in the Cabot Strait and other regions.....	10
5.0 References	12

LIST OF FIGURES

Fig. 1. Glider survey plan in DSZ C.....	4
Fig. 2. Realized glider trackline during the survey.....	6
Fig 3. Comparison between daily real-time North Atlantic right whale detections and number of upcalls recorded archivally by the hydrophone.....	8
Fig 4. Map and time series of visual and acoustic survey effort during 16 August through 22 October in DSZ C.	8

LIST OF TABLES

Table 1: Definitions of precision and recall rates calculated in this study.....	5
Table 2. Daily precision and recall comparing real-time and archival North Atlantic right whale detections.	9

TERMINOLOGY

DMON	Digital Acoustic Monitoring Instrument
LFDCS	Low-frequency Detection and Classification System
PAM	Passive Acoustic Monitoring
GSL	Gulf of St. Lawrence
TSS	Traffic Separation Scheme
NAVWARN	Navigational Warnings
DSZ	Dynamic Shipping Zone
CTD	Conductivity, Temperature, Depth Instrument
NASP	National Aerial Surveillance Program
RUDICS	Router-based Unrestricted Digital Interworking Connectivity Solution
CSD	Circuit Data Stream
GPS	Global Positioning System

1.0 INTRODUCTION

The Government of Canada is working to reduce the maritime sector's impact on the North Atlantic right whale (*Eubalaena glacialis*). Vessel strikes are one of the primary threats to the right whale population. One of the ways in which the government has been able to reduce the risk of vessel strikes is by implementing vessel traffic management measures, such as mandating reduced ship speeds in areas of high vessel traffic when right whales are detected, while permitting normal operational speeds when they are not detected (referred to as 'dynamic management'). Shipping lanes in the Laurentian Channel, Gulf of St. Lawrence (GSL) have been divided into Dynamic Shipping Zones (DSZ), and each DSZ has been managed annually since 2018 (Zones A, B, C and D) or 2019 (Zone E). Successful dynamic management that minimizes impact on industry in the DSZ is reliant on regular surveillance for whales. A 10-knot speed restriction may be implemented in a DSZ under one of two conditions: either a right whale is detected, or no surveillance effort occurred over a set period of time due to poor weather conditions. Before April 2020, the only monitoring method that had been used to detect right whales in real-time in the DSZ was aerial surveillance by the National Aerial Surveillance Program (NASP), whereby trained observers watched for visual indicators of right whales at the surface of the ocean. Like all whale monitoring tools, visual detection has some limitations; it is only possible during daytime hours and sufficiently good weather to be able to see the water surface (e.g., no fog) and accurately detect the whales (i.e. ability to distinguish a whale or its blow from whitecaps at the surface of the water), it relies on operators seeing the whales when the whales surface (right whales spend the majority of their time underwater), and it relies on aircraft availability, and is expensive relative to other detection platforms. Further, visual surveillance is known to underestimate right whale presence when low densities of whales are present because individual right whales are difficult to visually detect (Durette-Morin et al., 2019).

Cost-effective and accurate right whale detection solutions that complement visual monitoring are essential to improve the effectiveness of the DSZs. One goal of adding new monitoring tools is to reduce the impact of the operational measures on the shipping industry. If no survey effort is possible in a set seven-day period within a DSZ, then a precautionary speed limit is implemented by Transport Canada as a precaution in case whales are present. Since autonomous detection platforms such as gliders and buoys can monitor continuously 24 hours a day in all types of weather, precautionary speed limits should be implemented less often than with aerial surveillance alone, especially during spring and fall when inclement weather is more frequent.

Autonomous platforms such as buoys, moorings, and gliders are all being experimented with as tools to enhance right whale monitoring in this region. Passive acoustic monitoring (PAM) from omnidirectional hydrophones mounted on profiling electric gliders has been demonstrated to be effective at detecting right whale vocalizations automatically and relay the data to shore in near real-time (Baumgartner et al. 2013). Gliders are mobile autonomous vehicles that can be deployed for months at a time and tasked to repeatedly survey an area of ocean and persistently monitor for whales. The DSZs present some challenges to this approach, particularly the presence of ship noise that may mask acoustic signals, strike risk between vessels and gliders presented by the presence of ships near the gliders, and currents which can cause gliders to deviate from their course. Nonetheless, a pilot study conducted in 2019 in the Honguedo Strait proved these challenges were surmountable in this region with careful study design

and can provide useful and accurate information on the presence or absence of vocalizing whales in near real-time (Davies 2020).

The primary objective of this project was to deploy a glider in DSZ C in the Gulf of St. Lawrence in order to improve near real-time right whale monitoring effort in busy shipping lanes to reduce the risk of ship strikes during summer and fall of 2020. Empirical data were collected on right whale acoustic presence in near real-time using glider-mounted real-time PAM technology in DSZ C. Acoustic definite detections of right whales were used to trigger the 10-knot slowdown measure in the DSZs. The secondary objective of this project was to fly the glider along the shipping lane between DSZ C and the Cabot Strait to assess the feasibility of persistently monitoring this region with gliders in future years. The near-real-time performance statistics for the system were generated for the entire deployment through comparison with the archival acoustic information on the glider after it was retrieved.

2.0 Methodology

2.1 Observational Technology

2.1.1. Autonomous Electric Profiling Gliders

The autonomous platform used in this study was a Slocum G3 electric glider (Teledyne Webb Research, Schofield et al. 2007, Baumgartner et al. 2020). This long-endurance platform is battery powered and depending on the battery type, can remain on mission for up to nominally six months. For this deployment, the glider was equipped with a non-rechargeable lithium primary battery with nominally a three-and-a-half-month endurance. Gliders profile the water column in an undulating manner collecting science data along a pre-programmed track, and surfacing at intervals to obtain a GPS fix. They send a subset of the science and flight data to a shore station server, and if necessary, receive commands from a shore-based glider pilot. Gliders are equipped with an Iridium modem to transmit data and receive commands from shore via the global Iridium RUDICS network each time it surfaces. For this mission the glider was configured to surface every four hours to obtain a GPS fix and connect to Iridium. The surface interval is programmable, and four hours is a very typical interval that is a good temporal trade-off between sampling underwater and surfacing to send data. The engineless glider moves up and down in the water column by using a piston in its nose, known as a buoyancy pump, to change its density (and therefore buoyancy) relative to the surrounding water column. The glider used for this mission was equipped with a 350-m buoyancy pump, meaning it could reach a maximum depth of 350-m. The minimum sampling depth was set to 25-m which is below the draft of most vessels that transit in this region, to minimize collision risk. Slocum gliders can carry a variety of science sensors. For this mission, the glider carried two sensors, a pumped CTD (Seabird Scientific Ltd.) and a DMON omnidirectional hydrophone (SN 32, Johnson and Hurst 2007, Baumgartner et al. 2013, 2019). The hydrophone recorded and archived all acoustic data up to one kHz in frequency (which is well within the right whale sound repertoire frequency). Science and flight data were recorded at a one-Hz sampling rate.

2.1.2 Near Real-Time Acoustic Detection System

The project focusses on one type of technology that is now commonly used in Canadian waters to acoustically monitor the tonal calls of right, sei, fin, humpback, and blue whales in near real-time while simultaneously measuring environmental conditions. The technology consists of an omnidirectional digital acoustic monitoring (DMON) hydrophone and low frequency detection and classification system (DMON-LFDCS, Baumgartner et al. 2013, 2019, 2020). The technology has been used successfully to monitor baleen whales in near real-time on the Scotian Shelf and in the southern Gulf of St. Lawrence right whale habitats since 2014 and the USA since 2012. The DMON-LFDCS detects low-frequency (<one kHz) tonal sounds from an acoustic record and classifies the statistical attributes of the whale sounds through a comparison with a stored library of known calls pre-programmed into the glider software. A subset of the attribute and detection data (eight kb per hour) is sent to shore every four hours, where North Atlantic right, fin, humpback, and sei whale sounds are validated by an experienced analyst using a conservative and well-tested protocol (Baumgartner et al. 2020). Data are scored in 15-minute increments called tally periods. Scoring options are Definite Detection, Possible Detection or Not Detected based on the strength of the objective statistical data and contextual information in the 15-minute period (Baumgartner et al 2019, 2020). For this mission blue whale sounds were also recorded and noted to be prevalent in the acoustic record, and blue whales will be included in a future iteration of the real-time evaluation protocol. This protocol should result in a 0% false acoustic detection rate for North Atlantic right whales, but it can miss true right whale calls that were recorded by the glider (17.9% daily missed detection rate, Baumgartner et al. 2020), especially if such calls are rare. These can be later assessed post-recovery of the glider using the complete archival audio data. The glider recorded and processed all passive acoustic data while profiling and surfaced to transmit a subset of the whale detection and classification data to a shore station every four hours (see details in Baumgartner et al. 2013). The project principal investigator and her trained lab members validated the whale detections daily, seven days a week, during the deployment. Validated detections were disseminated via various automated systems for online publication, including WhaleMap¹, the Whale Alert App², and Robots4Whales³. The data were sent directly to the Transport Canada Situation Centre and Marine Safety and Security through automated email notification.

2.2 Mission Plan

The glider was deployed by technicians from a local whale watching vessel that departed from Baddeck, Cape Breton Island, Nova Scotia, on 16 August 2020 (Fig. 1).

2.2.1 Glider Flight Plan

¹ <http://whalemap.ocean.dal.ca>

² <https://whale-alert.io>

³ http://robots4whales.who.edu/twr0919/twr0919_capx638.shtml

The glider flight plan was divided into two parts. The first part of the survey took place from 16 August through 22 October (68 days). During this period, the glider surveyed Dynamic Shipping Zone C (Fig. 1). The flight plan was comprised of one transect, 46 nautical miles in length, that transited between the inbound and outbound shipping lanes (i.e., within the traffic separation area). Ten waypoints were positioned along this transect (Fig. 1) and these waypoints were programmed into the glider's flight computer to aid in glider navigation. The glider transited back and forth across this transect 12 times in 68 days. There is a five nautical mile buffer zone between DSZ B and C, and any right whale detections made while the glider was within in this zone triggered a speed limit in both DSZ B and C. The second part of the survey began on 23 October and continued until the glider was recovered on 12 November (21 days). During this time, it was intended that the glider would transit southeast from DSZ C in the traffic separation area to the Cabot Strait, before turning southwest and transiting along the western margin of Cape Breton Island to be recovered near shore from a vessel departing from Chéticamp, Nova Scotia (Fig. 1).

Two professional glider pilots from Teledyne Webb Research piloted the glider during deployment, adjusting the thruster, buoyancy engine and rudder parameters as needed to maintain course within +/- 10 km of the intended trackline (Fig. 2) while minimizing self-noise, to the extent possible. If the glider approached the boundary of a 10km buffer around the expected track, or deviated shallower than 100-m bathymetric depth, the pilots were directed to use the glider thruster to help return the glider to its trackline (so-called 'flyback' setting).

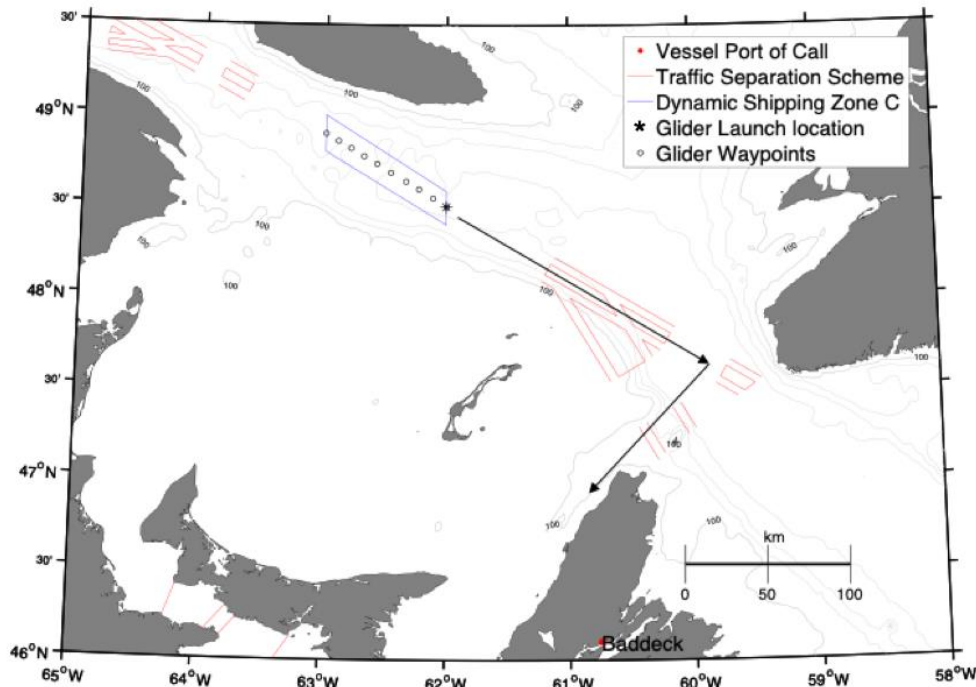


Fig. 2. Glider survey plan in DSZ C. Depicted are the deployment vessel's port of call (red symbol) at Baddeck, Cape Breton Island, the Traffic Separation Scheme (red lines), the boundary of DSZ C (blue polygon), glider launch location (black asterisk) and glider survey waypoints within DSZ C. The intended glider track during the return transit during the final weeks of the survey along the Cabot Strait is shown with two black arrows.

2.3 Data Analysis

Real-time detection scores for five species of baleen whales made by the glider were reported as either Definite, Possible, or Not Detected (see Section 2.1.2). After the platform was recovered, archived acoustic data was reviewed by a trained acoustic analyst using a desktop version of the LFDCS detection and classification software (Baumgartner and Mussoline 2011, see also Section 2.1.1 above). The LFDCS directed the analyst to possible North Atlantic right whale detections that were then reviewed audially and visually to make a final determination that a right whale was Present or Absent. At least three right whale upcalls had to be present on the archived acoustic record in a 24-hour period for the analyst to score that day as 'Present' (Davis et al. 2017, Durette-Morin 2021). A day was scored as 'Absent' if less than three calls were found on the archival record over a 24-hour period. Daily archival data was compared to daily real-time data to calculate precision (True Positive or True Negative) and recall (False Positive or False Negative) detection rates. In real-time, three classification levels are used: Definite, Possible and Not Detected. Precision and recall rates were calculated by comparing the three real-time classifications to two archival classifications (Present or Absent). In all rate calculations, the numerator is a detection classification in real-time, and the denominator is the detection classification from the archival record (Table 1). For example: True positive precision = $\frac{\text{Definite Detections in real time}}{\text{Present on archival record}} \times 100\%$.

Table 1. Definitions of precision and recall rates calculated in this study.

	True Positive	False Positive	True Negative	False Negative
Calculation	Real Time Definite / Archival Present	Real Time Definite / Archival Absent	Real Time Possible or Absent / Archival Absent	Real Time Possible or Absent / Archival Present
Measure:	Precision	Recall	Precision	Recall

Sightings and trackline data from the aerial surveys in the region were obtained to compare right whale acoustic detections on days when aerial surveillance occurred in DSZ C.

3.0 Results

3.1 Glider Flight Characteristics

The glider performed as expected during its survey of DSZ C. It made 12 transits over a 68-day period, averaging five and a half days to transit from one end to the other. The glider remained on its intended trackline within the traffic separation area and did not deviate into either the inbound or outbound shipping lanes while it was in DSZ C (Fig. 2).

On 23 October, the glider departed DSZ C to navigate between the shipping lanes along the Cabot Strait. The relatively narrow swath of ocean in the traffic separation area meant the glider had to maintain a fairly precise trackline to avoid transiting into either of the two lanes. On 25 October, when it reached

the approximate mid-point of DSZ E, it encountered a consistent northward current that pushed it into the inbound (north) shipping lane (Fig. 2). For the safety of the glider, the technicians moved the glider into the buffer zone to the north of the inbound shipping lane, where it remained until it entered the Cabot Strait. The thruster was not used during this transit. There were no further navigational issues within the Cabot Strait.

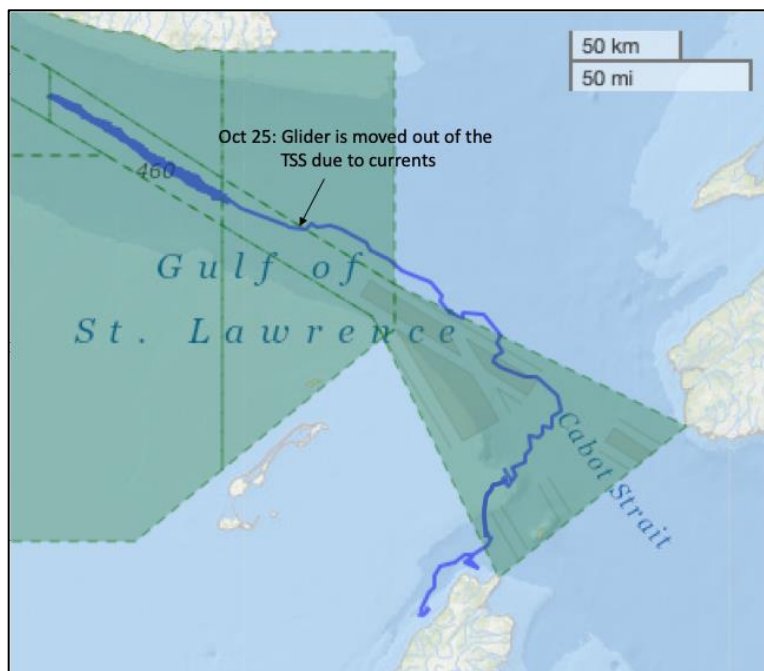


Fig. 2. Realized glider trackline (blue line) during the survey, in relation to the 2021 Transport Canada management areas (green polygons) and Cabot Strait Traffic Separation Scheme (gray lines and gray shaded areas). A black arrow points to the location where the glider was moved out of the TSS due to strong northward currents.

When positioning the glider for pick up on the west side of Cape Breton the glider entered a coastal current region and the current swept the glider closer to shore than its intended track. Manual piloting and the thruster were used to keep the glider offshore until it could be picked up by our recovery vessel. This was successful. When the thruster is turned on, the hydrophone records the mechanical sounds generated by the thruster and most other sounds are not audible, so no marine mammal sounds except a few minke whale clicks were recorded during the final ~ 48 hours of the deployment.

From 22 October through 27 October an interruption occurred in the Iridium satellite network. No real-time acoustic data were transmitted during this period. The iridium outage was an unintended consequence of a scheduled change in settings by the Iridium company. This caused a partial outage with RUDICS iridium communications that extended at least across North America and affected all deployed gliders across the continent. It is unclear why that setting was changed by the iridium service.

There are two ways to make iridium calls with the glider: a data connection via RUDICS to allow data transfers from the glider to a dockserver (preferred method), or having the glider's iridium modem call a

landline connected to a 56K modem to allow for the data connection (back-up method). Normally glider communication is made using the faster, more efficient RUDICS approach. The outage only affected the RUDICS data connection, while the landline call method was unaffected. However, because the landline system worked, the glider team managed to have the glider call into that line, and communications with the glider worked from then on. The backlog of real-time data was offloaded, and the acoustic analyst was able to review the entire backlog (though at a five day delay). It took the glider technical team several days to figure that out since it had never happened before. In the future it is not expected that an outage like this will affect the real-time data transmission. It did not affect the archival acoustic data at all.

3.2 North Atlantic right whale detections

3.2.1 Near Real-Time Detections and Dynamic Speed Limits

Definite detections of North Atlantic right whales were made on seven survey days (Fig. 3). Possible detections were made on an additional ten survey days (Fig. 3). Five of the seven days with definite detection were clustered during the first fourteen days of the deployment (August 16 through 29). All definite detections were made when the glider was within DSZ C. There were no definite right whale detections during the glider's transit back to shore along the DSZ E-Cabot Strait-Cape Breton route.

There were very few overflights (three) by aerial surveillance during the 68-day survey of DSZ C, so the dataset is not sufficient to make a robust comparison between visual and acoustic detections (Fig. 4). No visual detections were made by aerial surveillance during the three overflights of DSZ C. No acoustic detections were made on those three days by the glider.

Navigational warnings (NAVWARN) of a 10-knot speed limit in DSZ C were issued within 24 hours of a real-time acoustic detection if no speed limit had been in place at the time the detection was made. Acoustic detections that triggered a NAVWARN in DSZ C were made twice, on 16 August and 5 October (Fig. 3). NAVWARNs were then issued on 17 August and 6 October, respectively. The speed limit was first implemented on 17 August and this speed limit remained in effect until 14 September 2020, with the exception of three poor weather days during 26-29 August 2020 when it was temporarily lifted for navigational safety reasons. The second period when the speed limit was implemented began on 6 October and ended on 20 October, with the exception of three instances of six days total when it was temporarily lifted, once again due to bad weather conditions (Fig. 3). In total, the speed limit was in place in DSZ C for 32.5 days, or 47.8% of the 68-day survey period.

A NAVWARN was also issued for DSZ B on 23 August when the glider transited into the five nautical mile buffer zone between DSZ C and DSZ B and made a right whale detection there.

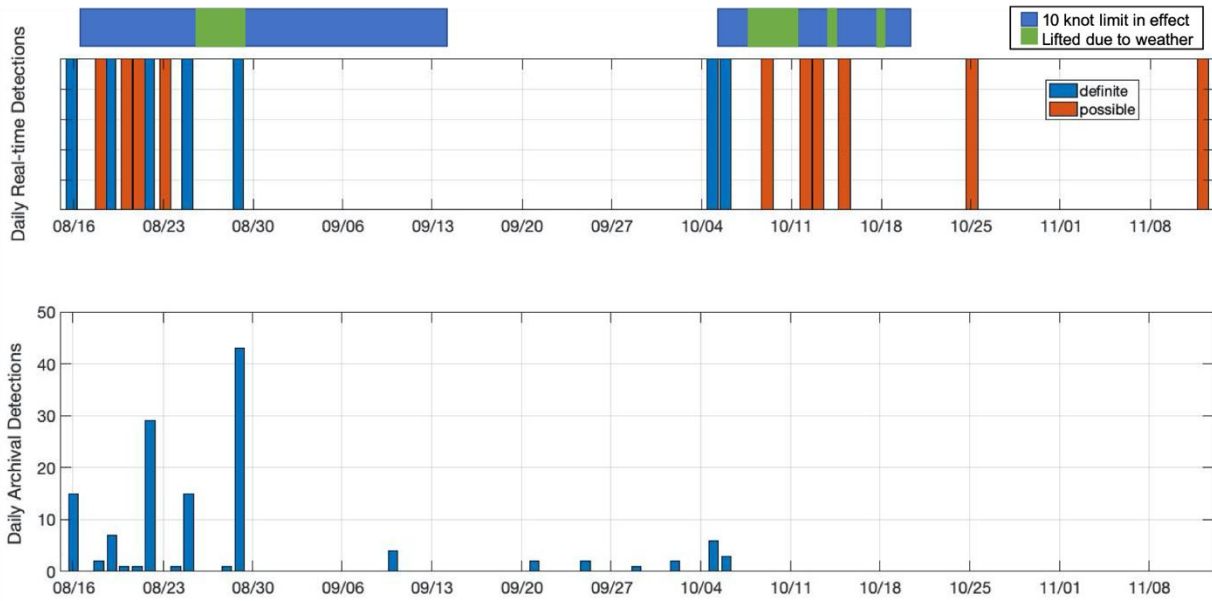


Fig 3. Comparison between daily real-time North Atlantic right whale detections (top panel) and number of upcalls recorded archivally by the hydrophone that were detected by audiovisual review after the deployment (bottom panel) in relation to the timing of the implementation and lifting of the slow zone in DSZ C (blue and green bar above the top panel). A minimum of three upcalls on per day in the Daily Archival Detections series is required to score right whales as present on that day (see Section 2.3).

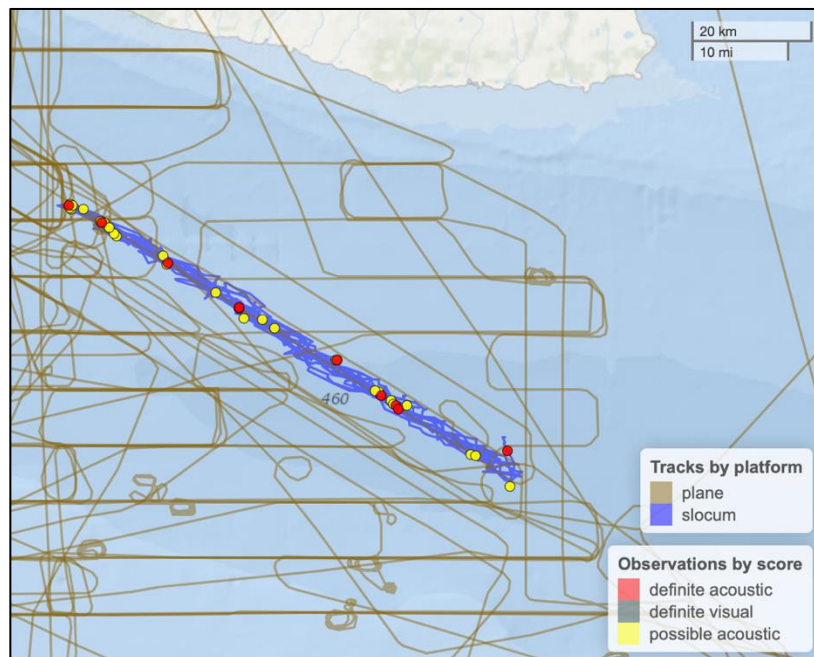


Fig 4. Map and time series of visual and acoustic survey effort during 16 August through 22 October 2020 in DSZ C.

3.2.2 Archival Acoustic Data Analyses

Right whales were scored as present on the archival acoustic record on eight days of the survey (Fig. 3). Right whales were present on the archival record on all seven days that they were scored as definitely detected in real-time, and on one day (10 September) when they were scored as not detected in real-time. This translates into a false positive rate of 0% and a false negative rate of 12.5% over the deployment (Tables 1 and 2). The number of upcalls on days when right whales were present ranged from three to 43 upcalls.

The missed detection on 10 September was due to the fact that the 8 kb per hour limit had been reached while the whale was calling, and those pitch tracks were not sent to shore (see Section 2.1.2). A slowdown in DSZ C had already been implemented on 10 September due to a detection that had been made 13 days earlier, on 29 August. This meant that the missed detection on that day did not translate into increased risk to the whales.

Possible detections were made on 10 days in real-time. Right whales were scored as absent on the archival record on all 10 of these days (Table 2). Six of these days occurred in the fall period (after 1 October) when humpback whales were calling, and the archival review of the data found that the possible right whale detections during this period were actually humpback whales.

Right whales were scored as not detected in real-time on 71 days and were confirmed archivally as absent on all 71 days.

Table 2. Daily precision and recall comparing real-time and archival North Atlantic right whale detections. Description of terms is provided in Table 1.

	Archival Present:	Archival Absent:
Real-time Definite	7	0
Real-time Possible	0	10
Real-time Not Detected	1	71
	Rates (%):	
True Positive	100	
False Positive	0	
True Negative	100	
False Negative	12.5	

4.0 Conclusions and Recommendations

4.1 System Performance

The glider flight performance and real-time detection system performance were within expectations during the deployment. The false positive and false negative rates for North Atlantic right whales are

nominally 0% and 17.9%, respectively (Baumgartner et al. 2020), which is consistent with the results of this study. Similar to the Honguedo Strait glider deployment (Davies et al. 2019), the glider was able to consistently navigate well along its intended track line while in DSZ C, and did not enter the shipping lanes, meaning risk to the glider was minimized with this survey design. In response to the glider detections, a speed limit in DSZ C was implemented for 47.1% of the survey period, which is a significant portion of the survey. The glider survey track transited between the west and east boundaries of DSZ C. This caused the glider to regularly transit into the five nautical mile buffer zone of DSZ B, which overlaps with DSZ C at its western boundary. On one occasion during the survey the glider was located in this buffer zone and made a right whale detection, causing a 10-knot speed limit to be implemented in both DSZ B and DSZ C. Taken together, the results indicate that the gliders are an effective monitoring method to support dynamic shipping management in DSZ C. It is expected that gliders could perform similarly in the other three DSZs in the Laurentian Channel (DSZ A, B or E) because the other three DSZs are similar in shape, size, orientation relative to ship traffic, currents, and bathymetry.

4.2 Glider Communications

Inquiries were made with the Iridium provider to strategize for the future in case additional outages occur. Through this inquiry, it was found that the cost of an Iridium RUDICS call is \$0.60 USD per minute. If the same modem is used to make a landline call to a 56k modem to send data (this was the solution when the Iridium outage occurred, described in Section 3.1) the rate is the same at \$0.60 USD per minute. So, it does not increase the cost if the glider technicians must default to the old modem during an Iridium outage. The bandwidth of the two is also the same, so data transfer rates should not change. RUDICS is still the most advantageous approach when it is available, which is almost always. Landline data transfer, which is also called Circuit Switch Data (CSD), works much the same way making a phone call does with the key difference being data is being communicated rather than voice; just as with phone calls, someone is required to be on the other end to “answer” the CSD call. RUDICS, on the other hand, offers an autonomous solution. New communications modem solutions are also coming soon to help advance communications bandwidth. The gliders are somewhat bandwidth limited for this application and the team did not have the glider send back audio data in real-time because it is too time expensive. There is a solution on the horizon a couple of years away that that will likely be of interest as it could address this issue.

4.3 Flight in the Cabot Strait and other regions

One of the goals of this mission was to determine how well gliders can navigate in the Cabot Strait region of the Gulf of St. Lawrence. Glider navigability in this region was within normal operating parameters, and the glider flight was locally affected in the short-term by currents off the west of Cape Breton and in DSZ E. Coastal currents are generally stronger than offshore currents and gliders should be kept a fair distance from shore as a precaution during deployment and recovery. The deployment was not persistent enough in any given region to characterize the full range of possible regional currents that a glider may encounter. Future deployments planned for the Cabot Strait region in summer 2021 will be

able to better characterize glider flight through repeated survey of regions of interest over monthly and seasonal time scales.

Profiling electric gliders can theoretically be flown almost anywhere in the Gulf of St. Lawrence. The research group has experience flying in the Shediac Valley region of the southern Gulf of St. Lawrence, as well as DSZ A, C and E of the Laurentian Channel, and the Cabot Strait. No environmental conditions have been found that would prevent successful profiling glider operations in any of these regions. It is normal to encounter local currents that cause navigability problems in the short-term (hours to days), but these are usually surmountable with some combination of creative survey planning, manual piloting, and thruster use. Glider teams must develop regional operational plans that take into account local environmental conditions and ship traffic patterns to maximize navigability and minimize strike risk to the glider. Gliders are 'designed to lose' in a collision with a boat, meaning the glider would very likely be destroyed in a collision, and so it is very important to minimize this risk.

Regional glider operational plans will vary in complexity and cost depending on a number of factors. To take full advantage of the autonomous capability of a glider, presumably it is not desirable to require a stand-by vessel at all times in case of emergencies such as the glider being swept close to shore. To avoid the need for a stand-by vessel in remote locations that are difficult to access by road, the research group generally do not to deploy the gliders into areas that are known to have high, persistent, and variable currents, and/or areas that are constrained on multiple sides by coastline (i.e., the Jacques Cartier Passage, Northumberland Strait, St. Lawrence Estuary or Strait of Belle Isle). Gliders can be deployed in these areas, but a technical team and a boat standing by on location would be a prudent precaution, and the cost of that would likely limit the length of a deployment.

For all other locations in the Gulf of St. Lawrence it is possible to fly gliders there. Slocum gliders can be equipped with 150 m, 300 m, or 1000 m buoyancy engines to fly optimally in different bathymetric zones. Generally, the Slocum gliders are most efficient at navigation in greater than 40-50 m of water. Each mission location would involve developing a regional operational plan detailing how the team would approach it and what kind of constraints and costs would be associated. Important logistical considerations include the deployment and recovery sites, deployment and recovery vessel, presence of ships and fishing gear that pose a risk to the glider, currents, and bathymetric depth. For example, a glider mission east of Newfoundland would be constrained by deployment locations and a plan in place for emergencies since it is remote. Other locations that may be interesting for Transport Canada to survey include the entirety of the Cabot Strait region, as well as the area between Prince Edward Island and the Magdalen Islands, which is a corridor in which right whales have been detected in the fall. There is a ferry that transits across this corridor.

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