TP 15580

Using passive acoustic monitoring from gliders for near real-time detection of North Atlantic right whales (*Eubalaena glacialis*) to inform management decisions related to the Laurentian Channel dynamic shipping zones and the Cabot Strait voluntary slowdown area (2021-2022)

Prepared for

the Innovation Centre

of Transport Canada

By: Dr. Frederick Whoriskey
Department of Biology, Ocean Tracking Network, Dalhousie University

Dr. Kimberley Davies
Biological Sciences, University of New Brunswick Saint John Campus

Mr. Adam Comeau
Coastal Environmental Observation Technology and Research group, Dalhousie University

Dr. Katherine Indeck
Biological Sciences, University of New Brunswick Saint John Campus

March 25th, 2022

NOTICES

Project Team:

Frederick Whoriskey, Dalhousie University, Project Lead

Kimberley Davies, University of New Brunswick, Co-Project Lead

Adam Comeau, Coastal Environmental Observation Technology and Research Group Glider Team Manager

Katherine Indeck, University of New Brunswick, Postdoctoral Fellow

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 and Véronique Nolet at the IC. The DMON hydrophone and real-time acoustic software and automated dissemination of real-time detections to partners were provided through collaboration with Dr. Mark Baumgartner at Woods Hole Oceanographic Institution. Dr. Baumgartner generously provided web support for this mission for which we are exceptionally grateful. The CEOTR glider team at Dalhousie University (Jude Van der Meer) expertly prepared, deployed and recovered the glider. Thank you to the vessel captains in Rivière-au-Renard and Cape Breton, as well as Fisheries and Oceans Canada, who supported deployment and recovery. We acknowledge 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. Finally, we thank Julianne Bonnell and Mark Baumgartner for consultations and advice with regards to interpreting challenging whale call records.

Un sommaire français se trouve avant la table des matières.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 15580	2. Project No. -	3. Recipient's Catalogue No. -
4. Title and Subtitle Using passive acoustic monitoring from gliders for near real-time detection of North Atlantic right whales (*Eubalaena glacialis*) to inform management decisions related to the Laurentian Channel dynamic shipping zones and the Cabot Strait voluntary slowdown area (2021-2022).		5. Publication Date March 25th, 2022 6. Performing Organization Document No. -
7. Author(s) Frederick Whoriskey, Kimberley Davies, Adam Comeau and Katherine Indeck		8. Transport Canada File No. -
9. Performing Organization Name and Address Dalhousie University 6299 South Street Halifax, N.S. B3H 4R2		10. PWGSC File No. HAL-0-85251 11. PWGSC or Transport Canada Contract No. T8009-200447/001/HAL
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

This project used right whale detections from gliders to trigger dynamic vessel management in the traffic separation scheme within Dynamic Shipping Zone C (DSZ C) and the Cabot Strait Voluntary Slow Zone. Two profiling gliders equipped with hydrophone systems were deployed for 116 and 107-day missions, respectively, from July 6th – November 9th, 2021. The gliders reported daily detections of four baleen whale species that were validated by a trained human analyst and then sent to Transport Canada. The glider detected right whales in DSZ C on fourteen survey days, and the Cabot Strait on two survey days. In response to the glider detections, a speed limit was imposed in DSZ C for 72 days, or 62.1% of the survey period. The false positive rates for right whale detections at the daily scale were 7% and 0%, and the false negative rates for this species at the daily scale were 5% and 1%, respectively.

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 35	23. Price -

CDT/TDC 79-005 Rev. 96

Canada

Transports Canada | Transport Canada

FORMULAIRE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada TP 15580	2. Nº de l'étude -	3. Nº 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 des baleines noires de l'Atlantique Nord (*Eubalaena glacialis*) pour supporter la gestion des zones de navigation dynamiques du chenal Laurentien et de la zone de ralentissement volontaire du détroit de Cabot (2021-2022).		5. Date de la publication 25 mars 2022 6. Nº de document de l'organisme exécutant -
7. Auteur(s) Frederick Whoriskey, Kimberley Davies, Adam Comeau and Katherine Indeck		8. Nº de dossier - Transports Canada -
9. Nom et adresse de l'organisme exécutant Université de Dalhousie 6299 South Street Halifax, N.S. B3H 4R2		10. Nº de dossier - TPSGC HAL-0-85251 11. Nº de contrat - TPSGC ou Transports Canada T8009-200447/001/HAL
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

Dans le cadre de ce projet, des détections de baleines noires ont été utilisées par les planeurs pour déclencher une gestion dynamique des navires dans le dispositif de séparation du trafic au sein de la zone de transport maritime dynamique (ZTMD) C et la zone de ralentissement volontaire dans le détroit de Cabot. Deux planeurs de profilage équipés d'un système d'hydrophone ont été déployés du 6 juillet au 9 novembre 2021 pour des missions durant respectivement 116 et 107 jours. Les planeurs ont signalé des détections quotidiennes de quatre espèces de baleines à fanons, qui ont été validées par un analyste formé, puis envoyées à Transports Canada. Le planeur a détecté des baleines noires dans la ZTMD C pendant quatorze jours de relevé, et dans le détroit de Cabot pendant deux jours de relevé. En réponse aux détections du planeur, une limitation de vitesse a été imposée dans la ZTMD C pendant 72 jours, soit 62,1 % de la période de relevé. Les taux de détection de faux positifs dans les signalements à l'échelle journalière étaient respectivement de 7 % et 0 %, et les taux de faux négatifs pour cette espèce à l'échelle journalière étaient respectivement de 5 % et 1 %.

17. Mots clés Baleine noire de l'Atlantique Nord, planeur, gestion dynamique, conservation des baleines, Zones de transport maritime dynamiques, Golfe du St. Laurent.	18. Diffusion Copie numérique

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	-	35	-

CDT/TDC 79-005 Rev. 96

Canada

EXECUTIVE SUMMARY

Multiple 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 included 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 to continue the use of gliders fitted with passive acoustic monitoring equipment (PAM) to detect and report in real time the calls and hence the presence of North Atlantic Right Whales (NARW; *Eubalaena glacialis*; hereafter right whales). The 2021 work builds on a 2019 pilot study that used PAM equipped gliders in the Honguedo Strait, and a subsequent expanded season of glider monitoring in the Gulf of St. Lawrence in 2020. This study was conducted in response to a request from Transport Canada to adopt autonomous mobile underwater gliders equipped to acoustically monitor for whale presence via whale calls. Since 2020, real-time whale detections collected both visually (from airplanes and an aerial drone) and acoustically using gliders have been used to implement ship slowdowns in the Gulf of St. Lawrence.

The primary goals of this project were to (1) use right whale detections made from a glider to trigger mandatory vessel slowdowns in the traffic separation scheme within dynamic shipping zone C (DSZ C) and (2) operate a second glider within the Cabot Strait voluntary slowdown zone to gather information on whale presence in this believed-to-be whale migration corridor. The performance of the gliders and their real-time reporting system during the deployment were evaluated.

In 2021, a profiling electric glider equipped with a hydrophone system capable of detecting and classifying right whale upcalls in real-time was deployed for a 116-day mission in the Laurentian Channel DSZ C from July 6th through November 9th. A second glider was deployed in the Cabot Strait voluntary slowdown zone for 107 days from July 19th through November 3rd. The gliders reported daily detections of five species of baleen whales, including right whales, that were validated by a trained human analyst. Right whale confirmed detections were distributed to Transport Canada to support any necessary management actions and for publication to the publicly available WhaleMap website.

During the DSZ C deployment, the glider made 14 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 14 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 (this could be extended if a detection occurred in the last seven days of a previously initiated slowdown). In response to the glider detections, the speed limit was in place in DSZ C for 72 days, or 62.1% of the entire survey period.

Part way through the DSZ C deployment, the glider suffered a system malfunction and was recovered on August 31st to assess the issue. Following resolution of the problem the glider was redeployed on September 10th. In addition, strong variable currents were encountered between August 18th through August 26th that slowed the progress of the glider compared to previous transects. The transit, in the

east to west direction, took 14 days compared to the anticipated 6 days, and required glider pilot intervention. All other navigational issues during the monitoring season were minor.

The Cabot Strait glider was deployed for a 107-day mission from July 19th to November 3rd where it performed 10 transits of an along-strait (AS) line and 10 transits of a cross-strait (CS) line. The average travel time for the AS line was 6 days and the average for the CS line was 4 days. From October 9th to October 18th during the final AS transit of the deployment, the glider encountered strong southeast currents that prevented it from making progress to the northernmost edge of the line. The pilots programed the glider to turn after 9 days of attempts and begin its final CS transect towards Cable Breton and its end-of-season retrieval. All other navigational and software issues were minor.

After the gliders were recovered, the raw audio data files that had been stored on board were analyzed in detail for the presence of right whale calls, with results from this analysis compared to the real-time reported data. The false positive detection rates in the real-time reports for right whale detections at the daily scale for the DSZ C and Cabot Strait gliders were 7% and 0% respectively, and the false negative rates for this species at the daily scale were 5% and 1%, respectively. These fall within normal operating parameters for this system. Thus, 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 that gliders can be successfully deployed to survey almost anywhere in the region although strong currents as described above can limit their progress.

SOMMAIRE

De multiples collisions entre baleines noires et navires ont eu lieu dans le golfe du Saint-Laurent depuis 2017. En réponse à cette situation, 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 provoqués par les détections visuelles en temps réel de baleines noires. La détection visuelle présente des limites importantes, notamment le fait de ne pas pouvoir être réalisée dans de mauvaises conditions météorologiques (vent fort, tempêtes) ou la nuit. Ce projet a été lancé pour poursuivre l'utilisation de planeurs équipés d'un matériel de surveillance acoustique passive (SAP) afin de détecter et de signaler en temps quasi réel les appels, et donc la présence, des baleines noires de l'Atlantique Nord (*Eubalaena glacialis*; ci-après baleines noires). Les travaux de 2021 s'appuient sur une étude pilote réalisée en 2019 à l'aide d'un planeur équipé d'un matériel de SAP dans le détroit d'Honguedo, ainsi que sur la saison suivante étendue de surveillance au moyen d'un planeur dans le golfe du Saint-Laurent en 2020. Cette étude a été menée en réponse à la demande de Transports Canada d'adopter des planeurs sous-marins mobiles autonomes équipés pour assurer une surveillance acoustique de la présence de baleines par l'intermédiaire de leurs appels. Depuis 2020, les détections de baleines en temps quasi réel, recueillies à la fois visuellement (à partir d'avions et d'un drone aérien) et acoustiquement, à l'aide de planeurs, ont été utilisées pour mettre en œuvre des ralentissements de navires dans le golfe du Saint-Laurent.

Les buts principaux de ce projet étaient (1) d'utiliser les détections de baleines noires réalisées à partir d'un planeur pour provoquer le ralentissement obligatoire des navires dans le dispositif de séparation du trafic au sein de la zone de transport maritime dynamique C (ZTMD C), et (2) d'utiliser un second planeur dans la zone de ralentissement volontaire du détroit de Cabot afin de recueillir des renseignements sur la présence de baleines dans ce qui est tenu pour être un couloir de migration des baleines. Les performances des planeurs et de leur système de signalement en temps quasi réel pendant le déploiement ont été évaluées.

Du 6 juillet au 9 novembre 2021, un planeur électrique de profilage équipé d'un système d'hydrophone capable de détecter et de classer les appels de baleines noires en temps réel a été déployé pour une mission de 116 jours dans la ZTMD C du chenal Laurentien. Un deuxième planeur a été déployé dans la zone de ralentissement volontaire du détroit de Cabot pendant 107 jours, du 19 juillet au 3 novembre. Les planeurs ont signalé des détections quotidiennes de cinq espèces de baleines à fanons, dont des baleines noires, qui ont été validées par un analyste formé. Les détections confirmées de baleines noires ont été communiquées à Transports Canada pour qu'il appuie toute mesure de gestion nécessaire et qu'il publie les donnes sur le site Web WhaleMap, qui est accessible au public.

Pendant le déploiement dans la ZTMD C, le planeur a effectué 14 passages sur le transect à travers le chenal situé entre les voies de navigation entrantes et sortantes de la zone de transport maritime dynamique C. Les déviations de trajectoire dues aux courants océaniques ont été minimes (nominalement < 1 mille nautique), et le planeur a pu se déplacer en toute sécurité entre les voies de navigation. Le planeur a réalisé des détections confirmées de baleines noires dans la ZTMD C pendant 14 jours de relevé. Une limitation de la vitesse à 10 nœuds a été mise en œuvre dans la ZTMD C dans les

24 heures suivant une détection en temps réel. Cette limite est restée en vigueur pendant 15 jours consécutifs (cette période aurait pu être prolongée si une détection avait eu lieu au cours des sept derniers jours d'un ralentissement précédemment mis en place). En réponse aux détections du planeur, une limitation de la vitesse a été mise en place dans la ZTMD C pendant 72 jours, soit 62,1 % de la période totale de relevé.

Au milieu du déploiement dans la ZTMD C, un système du planeur a subi un dysfonctionnement. Le planeur a été récupéré le 31 août afin d'évaluer le problème. Une fois le problème résolu, le planeur a été redéployé le 10 septembre. De plus, le planeur a rencontré de forts courants variables entre le 18 et le 26 août, ce qui a ralenti sa progression par rapport aux transects précédents. Le passage, dans le sens est-ouest, a duré 14 jours, contre les 6 jours prévus, et a nécessité l'intervention d'un pilote de planeur. Tous les autres problèmes de déplacement survenus au cours de la saison de surveillance étaient des problèmes mineurs.

Le planeur du détroit de Cabot a été déployé pour une mission de 107 jours, du 19 juillet au 3 novembre, au cours de laquelle il a effectué 10 passages d'une ligne le long du détroit et 10 passages d'une ligne de part et d'autre du détroit. La durée moyenne de déplacement pour la ligne le long du détroit était de 6 jours, alors qu'elle était de 4 jours pour la ligne de part et d'autre du détroit. Du 9 au 18 octobre, lors du dernier passage du déploiement le long du détroit, le planeur a rencontré de forts courants de sud-est qui l'ont empêché de progresser jusqu'à la limite la plus septentrionale de la ligne. Les pilotes ont programmé le planeur pour qu'il revienne après neuf jours de tentatives et qu'il entame son dernier transect de part et d'autre du détroit vers le cap Breton et sa récupération de fin de saison. Tous les autres problèmes de navigation et de logiciel étaient des problèmes mineurs.

Une fois les planeurs récupérés, les fichiers audio bruts stockés à bord ont été analysés en détail pour détecter la présence d'appels de baleines noirs. Les résultats de cette analyse ont été comparés aux données communiquées en temps réel. Les taux de détection de faux positifs dans les signalements en temps réel des détections de baleines noires à l'échelle journalière pour les planeurs de la ZTMD C et du détroit de Cabot étaient respectivement de 7 % et 0 %, et les taux de faux négatifs pour cette espèce à l'échelle journalière étaient respectivement de 5 % et 1 %. Ces chiffres sont conformes aux paramètres de fonctionnement normaux de ce système. Les objectifs de la mission ont donc été remplis 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 avec succès pour effectuer des relevés presque partout dans la région, même si les forts courants décrits ci-dessus peuvent limiter leur progression.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

TERMINOLOGY

AS	Along-Strait
CEOTR	Coastal Environmental Observation Technology and Research group
CS	Cross-Strait
CTD	Conductivity, Temperature, and Depth measurement instrument
DMON	Digital Acoustic Monitoring Instrument
DSZ	Dynamic Shipping Zone
GPS	Global Positioning System
GSL	Gulf of St. Lawrence
G3s	Current model of Slocum glider commercially available
G3	Next most advanced model of Slocum glider, but production discontinued
LFDCS	Low-Frequency Detection and Classification system
NASP	National Aerial Surveillance Program
NAVWARN	Navigational Warnings
PAM	Passive Acoustic Monitoring
RUDICS	Router-based Unrestricted Digital Interworking Connectivity Solution communications system
TSS	Traffic Separation Scheme

1.0 INTRODUCTION

The Government of Canada is working to reduce the maritime sector's impact on the North Atlantic right whale (*Eubalaena glacialis*) in Canadian waters. Along with entanglements in fishing gear, 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 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 implemented annually since 2018 (Fig. 1).

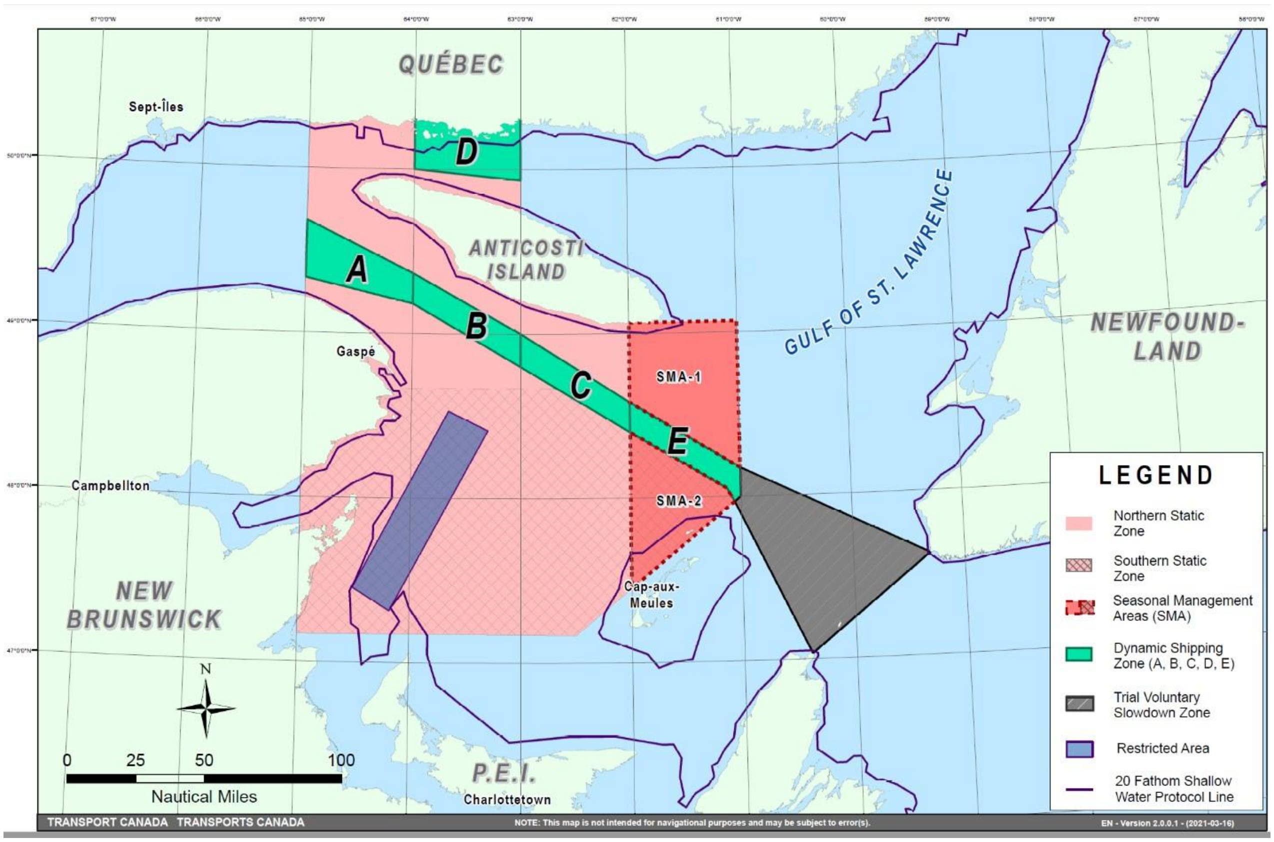

Fig. 1. Map of the 2021 Gulf of St. Lawrence vessel management system area showing the dynamic shipping zones and the various management measures implemented to protect right whales. Map produced by Transport Canada (https://www.dfo-mpo.gc.ca/fisheries-peches/commercial-commerciale/atl-arc/narw-bnan/2021/right-whale-baleine-noires-0518b-eng.html).

Dynamic management that minimizes impact on industry 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 within its boundaries, or as a precaution where no surveillance effort can occur in a zone 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, whereby trained observers watched for visual indicators of right whales at the surface of the ocean. Like all whale monitoring tools, visual detection has limitations; it is only possible when the surface of the water is visible during daytime hours and in the absence of fog. It requires wind speeds at the surface of the water that are sufficiently slow to allow observers to distinguish a whale or its blow from whitecaps. It also relies on operators seeing the whales when they surface (right whales spend the majority of their time underwater), relies on aircraft availability, and is expensive relative to other detection platforms. Finally, visual surveillance is known to underestimate right whale presence when low densities of whales occur because individual right whales are difficult to visually detect (Durette-Morin et al., 2019).

In addition to the DSZs, a trial seasonal voluntary slowdown (10 knot speed restriction; Fig. 1) was implemented in an area within the Cabot Strait during spring and fall in 2020 (April 28th – June 15th and October 1st – November 15th) and 2021 (April 28th – June 29th and September 29th – November 15th). Very little is known about the seasonality and spatial distribution of right whale use in this area (e.g., Crewe et al. 2021), however, it is believed that the Strait represents the major migration corridor for right whales accessing the Gulf during their spring-autumn feeding period. To date, real-time detections have not been used in this area to implement mandatory slowdowns, as there was no knowledge of when and for how long whales are present in the Cabot Strait. The glider work monitoring for right whale calls in the Cabot Strait will continue in 2022 to provide much-needed data on right whale presence in the area, which will inform future management measures.

Autonomous platforms such as buoys, moorings, and gliders are all being used as tools to enhance right whale monitoring in the Gulf of St. Lawrence. Gliders are mobile autonomous vehicles that can be deployed for months at a time and tasked with repeatedly surveying an area of ocean to persistently monitor for whale calls using passive acoustic monitoring (PAM) from omnidirectional hydrophones. This technology has been demonstrated to be effective at detecting right whale vocalizations automatically and relaying the data to shore in near real-time (Baumgartner et al. 2013). Acoustically monitoring the DSZs with gliders presents challenges, notably ship noise that may mask whale calls, the risk of collision between vessels and gliders when the gliders surface to transmit data, and currents that can cause gliders to deviate from their planned courses. Nonetheless, a pilot study to assess the feasibility of using glider technology near busy shipping lanes, conducted in 2019 in the Honguedo Strait, proved that these challenges were surmountable with careful study design and that gliders can provide useful and accurate information on the presence of vocalizing whales in near real-time (Davies 2020).

The primary goals of this year's work were to (1) use right whale detections made by a glider to trigger mandatory vessel slowdowns in the traffic separation scheme within DSZ C, and (2) deploy a second glider in the Cabot Strait voluntary slowdown zone to gather information on whale presence in this believed-to-be whale migration corridor. To accomplish this, the project tapped into the glider fleet and experienced glider personnel of Dalhousie University (Davis et al. 2018) and the expertise of the Davies' laboratory at the University of New Brunswick (Davies 2021).

2.0 METHODOLOGY

2.1 Observational Technology

2.1.1. Autonomous Electric Profiling Gliders

The autonomous platforms used in this study were Slocum electric gliders (models G3 and G3s; Teledyne Webb Research, Schofield et al. 2007, Baumgartner et al. 2020). The G3s model has replaced the G3 model, which is no longer sold. Both the G3 and G3s gliders are battery powered, long-endurance platforms and, depending on the battery type, can support a deployment length of four to six months. For this project's deployments, the two mission gliders were equipped with non-rechargeable lithium primary extended batteries to provide maximum time at sea. A third glider was prepped and held on shore to be ready on short notice to replace either of the mission gliders should they malfunction. Gliders profile the water column in an undulating manner, moving up and down by using a piston in their nose, known as a buoyancy pump, to change their density (and therefore, buoyancy) relative to the surrounding water (Fig. 2). They collect science data along a pre-programmed track and surface at fixed intervals. At the surface, they obtain a GPS fix, 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 (Router-based Unrestricted Digital Interworking Connectivity Solution) network each time they surface. For this project, the gliders were configured to surface every four hours. The surface interval is programmable, and four hours is a typical interval that is a good temporal trade-off between collecting data underwater and surfacing to send data.

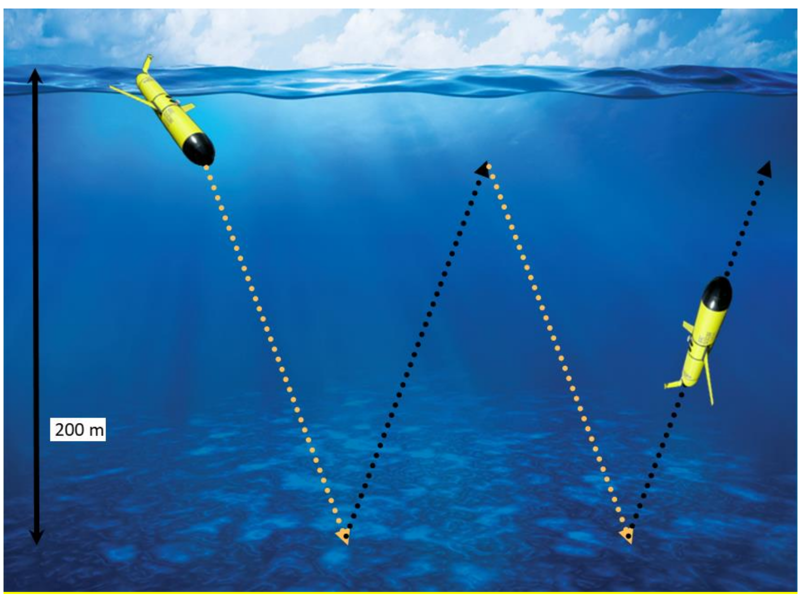

Fig. 2. Schematic showing the flight pattern of a Slocum glider.

The gliders used for this mission were each equipped with a 350-m buoyancy pump, meaning they could reach a maximum depth of 350-m. To minimize collision risk, the minimum sampling depth was set to 25-m, which is below the draft of most vessels that transit in this region. Slocum gliders can carry a variety of science sensors. For this mission, the gliders each carried four sensors including a CTD (pumped CTD Seabird Scientific Ltd. on the glider sampling in the DSZ-C; unpumped CTD, RBR Ltd. on the glider sampling in the Cabot Strait), an oxygen sensor (Aanderaa data systems), an acoustic tag receiver (Innovasea Systems Inc.), and a DMON omnidirectional hydrophone (Johnson and Hurst 2007, Baumgartner et al. 2013, 2019). The hydrophone recorded and archived all acoustic data up to one kHz, which is well within the frequency range of the right whale call repertoire. Environmental (science) data and statistics on the operating status and parameters of the glider (flight data, such as battery status, compass heading and GPS positions) were recorded between a 0.2 and 1 Hz sampling rate.

2.1.2 Near Real-Time Acoustic Detection System

The project employed a 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 a glider-mounted omnidirectional digital acoustic monitoring (DMON) hydrophone and a low frequency detection and classification system (DMON-LFDCS, Baumgartner et al. 2013, 2019, 2020), which automatically detects the call signatures of different species in the audio data. This 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 has been operational in the USA since 2012.

The DMON-LFDCS detects low-frequency (<1 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 when the glider surfaces approximately 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 project, 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, as any information on this endangered species' distribution is valuable from a conservation standpoint. 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, especially if such calls are low amplitude or rare. Generally, a 17.9% daily missed detection rate is anticipated based on previous studies (Baumgartner et al. 2020). Specifically, last year's work in the Gulf of St. Lawrence resulted in a 12.5% daily missed detection rate (Davies 2021). These rates can be assessed post-recovery of the glider using the complete raw archival audio data.

For this project, 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 WhaleMap[1], the Whale Alert App[2], and Robots4Whales[3]. The data were sent directly to the Transport Canada Situation Centre and Marine Safety and Security through automated email notification. Based on these notifications, appropriate vessel management measures (i.e., slowdowns) were implemented or extended by Transport Canada when a right whale was acoustically detected within the limit or buffer zone of DSZ C.

[1] http://whalemap.ocean.dal.ca
[2] https://whale-alert.io
[3] http://robots4whales.whoi.edu/twr0919/twr0919_capx638.shtml

2.2 Mission Plan

For the 2021 field season, gliders were operated in two areas: the DSZ C (a G3 glider), as well as the Cabot Strait region (a G3s glider). The glider monitoring the DSZ C will be referred to as the DSZ glider and the glider monitoring the Cabot Strait region will be referred to as the Cabot Strait glider.

2.2.1 Glider Flight Plan

There were two flight plans developed, one for each region monitored.

DSZ C/E

The DSZ glider arrived at its deployment location on the eastern end of DSZ E on July 6th, 2021, transported by the vessel “Island Venture 1” (Fig. 3). After a series of pre-deployment checks to confirm the glider was in good working order, it was deployed and began monitoring for right whales while transiting west to DSZ C. Once it arrived at DSZ C on July 13th, it began a repeated transits of a 46 nautical mile transect between the western and eastern boundaries of DSZ C. On October 31st, the glider completed its last transect of DSZ C and began its journey back to shore to the planned recovery location. The glider was recovered on November 9th from the chartered fishing vessel “L’Intrepid”.

Partway through this mission, the glider suffered an important system malfunction and required recovery to assess the issue. The glider was retrieved on August 31st from the Canadian Coast Guard Ship “Teleost” and after servicing was redeployed on September 10th from the chartered fishing vessel “Jordan C”. In total, this glider spent 125 days dedicated to this mission, including the nine days during which it was under repair for its system malfunction. See Fig. 3 for deployment and recovery locations, and Table 1 for a summary of deployment and recovery dates.

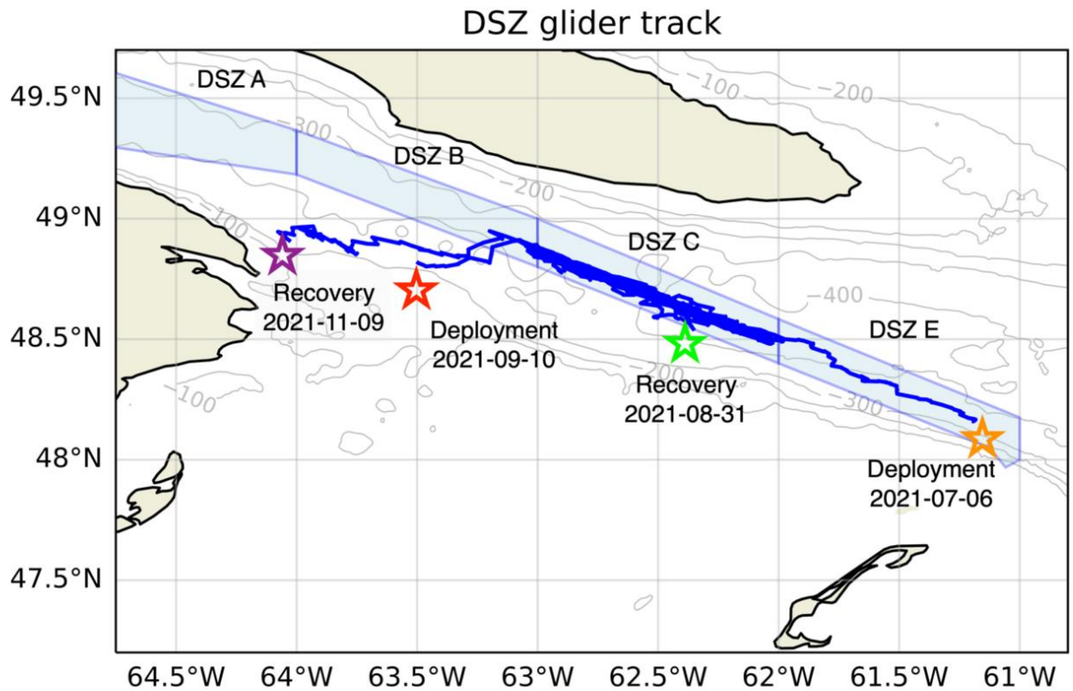

Fig. 3. 2021 locations of the DSZ C and DSZ E in relation to the glider track in dark blue. Bathymetry contours are displayed every 100 meters. Orange star: deployment on July 6th, green star: recovery on August 31st, red star: deployment on September 10th, yellow star: recovery on November 9th. Map produced by Dalhousie University's CEOTR group.

Cabot Strait

The Cabot Strait glider was transported to its deployment location off the coast of Cape Breton on July 19th, 2021, with the Ocean Tracking Networks rigid hull inflatable boat (RHIB) "Ocean Tracker". Once released after pre-deployment checks, the glider transited to arrive at the southern end of the 32 nautical mile (59 km) along-strait (AS) transect on July 23rd. The glider then followed a V-shaped transect, incorporating along-strait and cross-strait (CS; 35 nautical miles, 65 km) lines (Fig. 3). While performing the CS transect, the glider had to cross three shipping lanes. Since these shipping lanes pose a threat to gliders, efforts were made to minimize the time the gliders spent near the sea surface by pausing near real-time data transfer when the gliders transited across each shipping lane.

On the last AS transect, while heading to the North-East, the glider encountered strong currents and could only reach the midpoint of the transect before it had to begin its transit back towards shore on October 31st to the designated recovery location. It was recovered on November 3rd from the "Ocean Tracker" after having spent 107 days on mission. See Fig. 4 for deployment and recovery locations of the Cabot Strait glider, and Table 1 for a summary of deployment and recovery dates.

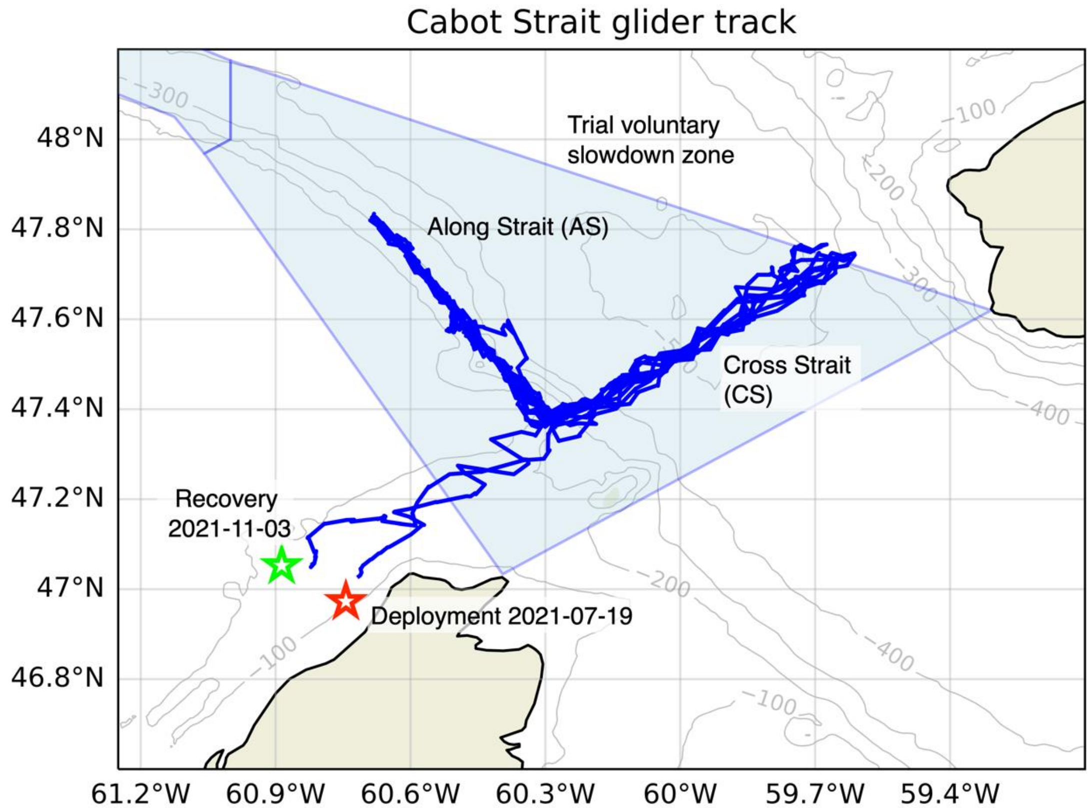

Fig. 4. 2021 locations of the along-strait (AS) and the cross-strait (CS) transect lines in relation to the glider track in dark blue. Bathymetry contours are displayed every 100 meters. Red star: deployment on July 19th, green star: recovery on November 3rd. Map produced by Dalhousie University's CEOTR group.

Table 1. Recovery and deployment dates.

Area covered	DSZ before malfunction	DSZ after malfunction	Cabot Strait
Deployment date	2021-07-06	2021-09-10	2021-07-19
Retrieval date	2021-08-31	2021-11-09	2021-11-03
Days at sea	56	60	107

The CEOTR glider team piloted the gliders during the deployments and adjusted the gliders' mission parameters as needed to maintain course within +/- 10 km of the intended track lines. Both gliders were set to inflect 25 m from the sea surface to remain under the draft of ships and 12 m from the sea floor. The surfacing interval was set to every four hours except for when the gliders were transiting below shipping lanes, at which point surfacing was set to every 6 hours, although these could run to 20 h. The amount of time the glider spent at the surface varied as a function of where the glider popped up, what Iridium satellites were in range while the glider was at the surface, and the amount of data that the glider had to transfer. For surfacing in shipping lanes only for navigation fixes with no data transfer the surface time was about 1 min. Surface times for data uploads outside of the shipping channels were typically about 10 min after a 4-h submergence period, but could run up to 45 mins after a 20 h submergence to cross the shipping lanes. The glider settings were optimized to maintain ascent and descent velocities less than 15 cm/second to minimize self-noise, to the greatest extent possible, unless increased speed was needed operationally to avoid obstacles. The thruster was only used on rare occasions as needed for the safe operation of the glider, and a log was created of its use (Table 2).

Table 2. Thruster log table.

Glider	**Thruster power (watts)**	**Time on (UTC)**	**Time off (UTC)**	**Reason**
DSZ glider	4	2021-08-29 17:22:30	2021-08-29 22:24:45	Used to propel the glider after a malfunction released the ejection weight
DSZ glider	4	2021-08-29 22:39:46	2021-08-29 23:26:23	Used to propel the glider after a malfunction released the ejection weight
DSZ glider	4	2021-08-29 23:32:42	2021-08-30 00:46:17	Used to propel the glider after a malfunction released the ejection weight
DSZ glider	4	2021-08-30 11:09:11	2021-08-31 04:46:26	Used to propel the glider after a malfunction released the ejection weight
DSZ glider	5	2021-11-09 09:54:00	2021-11-09 11:20:55	Thruster activated to fight currents while transiting to recovery location
Cabot Strait glider	1.5	2021-11-01 20:26:44	2021-11-02 12:15:01	Thruster activated to fight currents while transiting to recovery location
Cabot Strait glider	5	2021-11-02 12:15:01	2021-11-02 16:01:33	Thruster activated to fight currents while transiting to recovery location
Cabot Strait glider	3	2021-11-03 00:04:00	2021-11-03 14:28:09	Thruster activated to fight currents while transiting to recovery location

2.3 Data Analysis

Real-time detections of four species of baleen whales were classified by the gliders' LFDCS and subsequently validated by the on-shore analysts as either 'definite', 'possible', or 'not detected' (see Section 2.1.2). After the gliders were recovered at the end of a deployment, archived raw acoustic data were uploaded and 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 of whether a right whale was 'present'. For the purposes of assessing real-time detection performance, a minimum of three right whale upcalls had to be present in the archived acoustic record in a 24-hour period for the analyst to score that day as having right whales present (Davis et al. 2017, Durette-Morin 2021). This 3-call standard has been established as the minimum threshold required to be entirely confident that right whales are definitively present (Davis et al. 2017). Because of the costs to the shipping and fishing industry of taking action to protect whales, the 3-call protocol ensures that these measures are only triggered when there is 100% certainty a right whale is present. Further, this study's protocol required at least 3 calls in a 15-minute period to be transmitted in real-time in order to score 'detected' for a survey day. The upcall is the best call to identify right whales because it is a contact call used by all ages and sexes. However, it is highly variable within the species and similar to calls of other baleen whales (e.g., humpbacks). When fewer than three calls are recorded in 24 h, there a possibility of misidentifying a call from another species as a right whale, resulting in a false positive detection (Davis et al. 2017). For similar reasons, a day was scored as right whale calls being 'absent' from the archival record if less than three calls were found in the archival record over a 24-hour period.

Daily archival data were compared to daily real-time data to calculate detection rates for true positives, true negatives, false positives or false negatives (Table 3). Detection rates were calculated for these four categories by comparing the three real-time classification types (definite, possible, or not detected) to the two archival classifications (present or absent). In all rate calculations, the numerator is the number of detection classifications in real-time, and the denominator is the number of detection classifications from the archival record (Table 3). For example:

$$\text{True positive detections} = \frac{\text{Definite detections in real time}}{\text{Detections in the archival record}} \times 100\%$$

In these calculations, real-time possible detections are treated as 'absent' because levels of confidence in them indicating the true presence of a right whale are low.

Table 3. Definitions of detection 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

3.0 RESULTS

3.1 Glider Flight Characteristics

DSZ

During 2021, the glider deployed in the DSZ region performed one east-to-west transit of DSZ E and 14 transits of DSZ C over a period of 116 days at sea. The average number of days to travel from one end of DSZ C to the other was six days. The glider only partially completed its final transit as it was required to turn and head to its predetermined retrieval point for recovery as the end of the right whale monitoring season in the Gulf of St Lawrence approached.

During the initial deployment, a glider malfunction occurred that caused the ejection weight to discharge on August 29th. This rendered the glider unable to dive sufficiently for controlled flight and precipitated an emergency recovery mission. The glider drifted with the currents until August 31st when it was recovered. During the malfunction, the thruster was used to keep the glider underwater to minimize the risk of a glider-vessel collision. See the thruster log (Table 2) for a detailed description of when the thruster was on.

On several occasions, the glider travelled into DSZ B. Each instance can be grouped into one of three contexts, as follows: (1) on July 5th, August 5th, and from August 23rd to 25th, the glider transited up to 2.5 nautical miles into DSZ B due to a piloting miscommunication about the location of the western boundary of DSZ C. Once this error was corrected the glider remained in DSZ C while performing its regular transects. (2) On September 12th, the glider transited through DSZ B while progressing toward DSZ C as it returned to its planned station following its repairs and redeployment. (3) On October 30th, the glider transited through DSZ B while traveling to the recovery position.

Strong variable currents were encountered between August 18th and 26th that slowed the progress of the glider. The east-to-west transit at this time took 14 days, compared to the average six days during the rest of the deployment. To overcome these currents, the buoyancy engine volume was increased slightly to increase the glider's speed.

On October 25th, the glider deviated from its planned course into the southern shipping lane of DSZ C due to strong currents. The glider made its way northward to its programmed waypoints once the currents lessened, with no intervention from the glider pilots.

When positioning the glider for recovery from the Gaspé Peninsula, the glider encountered a strong current. On November 9th, the glider's thruster was turned on for 1.5 hours prior to recovery to prevent the glider from being swept away from the recovery site by the current (Table 2).

Cabot Strait

The glider performed 10 transits of the AS line (59 km) and 10 transits of the CS line (65 km) over a period of 107 days. The AS transect is 32 nm long and the glider took 6 days on average to transit it. The CS transect is 35 nm long and the glider took 4 days on average to transit it. Despite the AS transect being 3 nm shorter the increased transit time reflects a lower efficiency of the buoyancy engine in shallower waters and stronger currents towards the northern end of the transect.

During the AS transit from October 9th through October 18th, the glider encountered a strong, persistent current that prevented forward progress to the northern limit of the AS line. The glider was piloted east of the AS line into deeper water in an attempt to better fight the current. However, after 9 days of attempts with no progress, the glider was directed to the south of the AS line and began its CS transit.

A software issue occurred with this glider that caused it to quit its programed mission and attempt to hold its current position. This arrested forward progress and temporarily increased battery usage. The bug did not manifest itself during initial pre-deployment testing. Early on in the mission this issue caused the glider to hold station for 2 hours during one incident and 3 hours in a second. In both cases the glider required pilot remote intervention before returning on mission. Although the bug affected the glider every 7 to 14 days, the team programed the glider to automatically re-initialize its main mission every time this bug occurred. Once this setting was activated the glider no longer ran its station holding program due to this bug.

When positioning the glider for pick-up on the west side of Cape Breton, the glider entered a strong coastal current. Based on last year's transit in this area, this current was anticipated, the glider's course was adjusted, and the thruster was used to prevent it from getting pushed into shore. The thruster was used from November 1st through November 3rd, as reported in Table 2.

3.2 North Atlantic right whale detections

3.2.1 Near Real-Time Detections and Dynamic Speed Limits

DSZ

Definite detections of North Atlantic right whales were made on 14 survey days (Fig. 5). Possible detections were made on an additional 30 survey days (Fig. 5). Eleven of the 14 days with definite detections were concentrated within five weeks of each other, relatively early in the deployment (July 20th through August 24th). Most definite detections were made when the glider was within DSZ C, but three detections on 24 August were made when the glider travelled into DSZ B. There were no definite right whale detections during the glider's single transit through DSZ E at the start of the deployment.

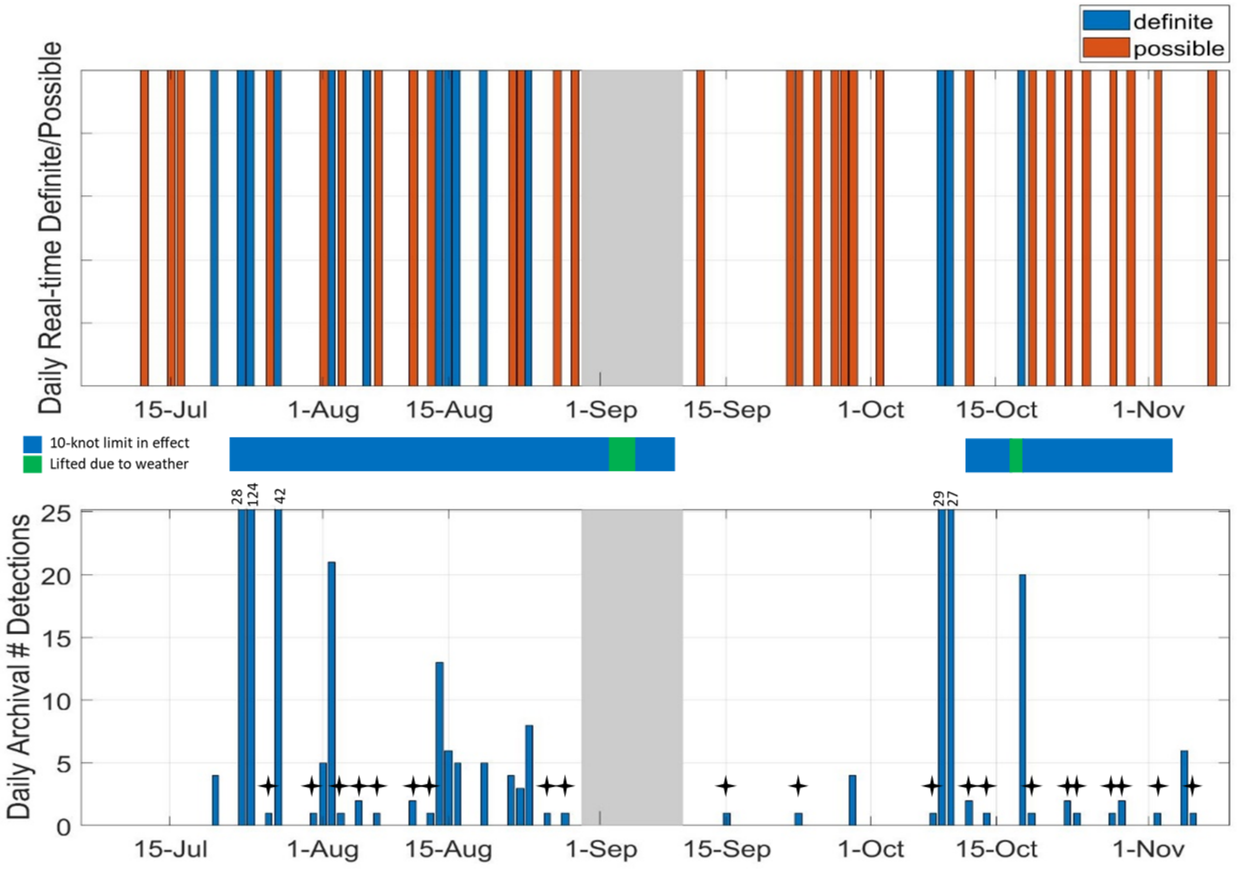

Fig. 5. Comparison for the DSZ glider between daily real-time North Atlantic right whale upcall detections (top panel) and the number of calls detected by audiovisual review of the archival data after the deployment (bottom panel). The implementation and lifting of the slow zone in DSZ C are shown by the blue and green bar between the two panels. A minimum of three upcalls per day in the Daily Archival Detections series is required to score right whales as present on that day (see Section 2.3). The stars indicate days when less than three upcalls were detected in the archival record. The grey shading indicates when the glider was out of the water due to a malfunction. Note: the y-axis has been condensed to allow an easier interpretation of call counts for the majority of days; days with call counts that exceeded 25 show the total number above the top axis.

Although there were over 50 days during the 116-day deployment when aerial surveillance was conducted over or near the shipping lanes, no visual observations of right whales were made within DSZ C (Fig. 6).

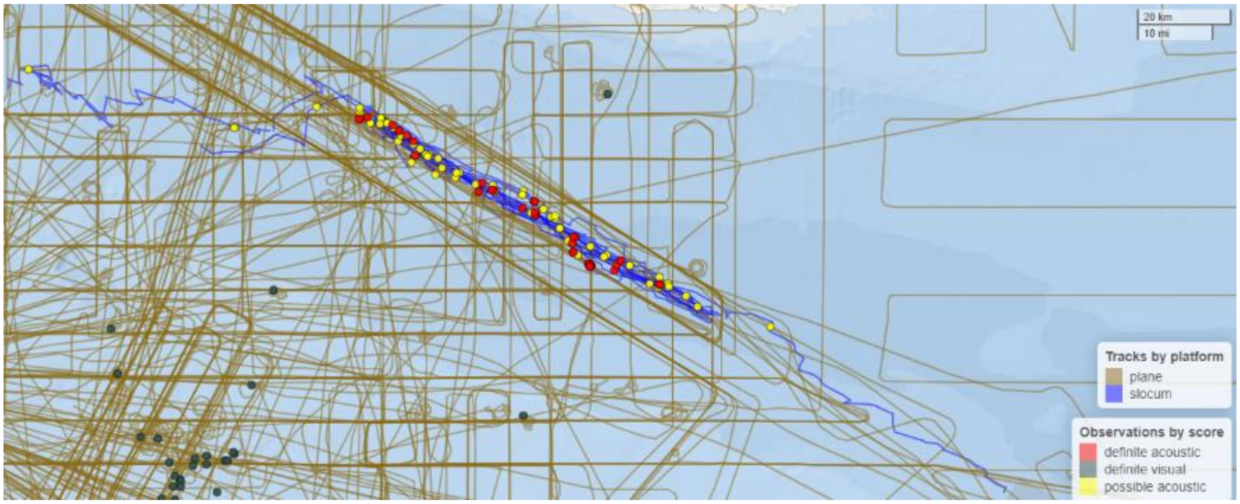

Fig. 6. Map and time series of visual and acoustic survey effort between July 6th and November 9th, 2021, in DSZ C/E. Map produced using open-access layers on the WhaleMap (Johnson et al. 2021) internet site (https://whalemap.org/).

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. If a speed limit was already implemented when a new real-time acoustic detection was made, the speed limit was reset for an additional 15-day period starting on the day of the new detection, provided the new detection occurred in the last seven days of a previous slowdown. Acoustic detections resulted in 72 days of speed restrictions in DSZ C over the 116-day deployment (Fig. 5). The speed limit was first implemented on July 22nd and this slowdown remained in effect until September 9th, 2021, except for a period between September 2nd to 4th when it was temporarily lifted for navigational safety reasons. The second period when the speed limit was implemented began on October 12th and ended on November 3rd, apart from one day when it was temporarily lifted, once again due to bad weather conditions affecting navigational safety (Fig. 5). In total, the speed limit was in place in DSZ C for 62.1% of the 116-day glider deployment period. Slowdowns for DSZ B were also implemented on August 6thand 26th when the glider transited into the five nautical mile buffer zone between DSZ C and DSZ B and reported definite right whale detections there.

Cabot Strait

Definite detections of North Atlantic right whales were made on two survey days (Fig. 7). Possible detections were made on an additional 13 survey days (Fig. 7). The two days with definite detections occurred in one 48-hour period near the end of the deployment (October 19th and 20th). The definite detections were made when the glider was on the western end of the cross-strait transect (Fig. 8).

There were over 30 days during the 107-day glider deployment when aerial surveillance was conducted over or near the Cabot Strait (see Fig. 8 for aerial surveillance coverage). However, there were only three visual observations of right whales in close proximity to the along-strait transect (between

October 13th and 26th), although these included one occasion when definite visuals occurred the same day as definite acoustic detections.

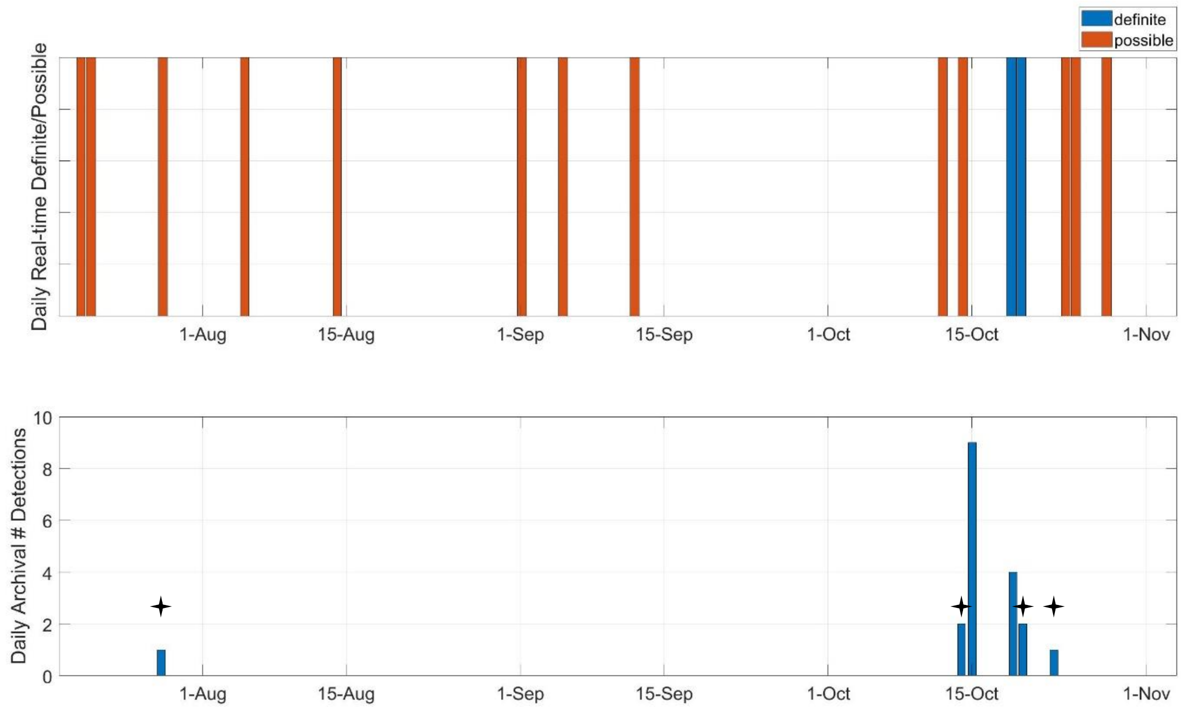

Fig. 7. Comparison for the Cabot Strait glider between daily real-time North Atlantic right whale upcall detections (top panel) and the number of calls detected by audiovisual review of the archival data after the deployment (bottom panel). A minimum of three upcalls per day in the Daily Archival Detections series was required to score right whales as present on that day (see Section 2.3). The stars indicate days when less than three upcalls were detected in the archival record.

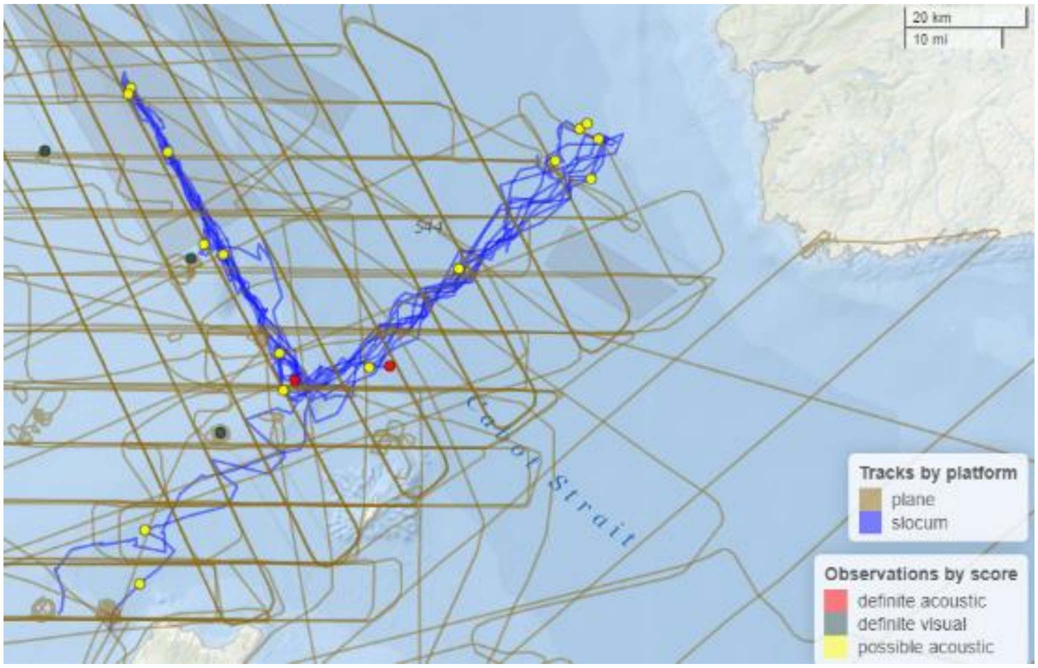

Fig. 8. Map and time series of visual and acoustic survey effort between July 19th and November 3rd, 2021, in Cabot Strait. Map produced using open-access layers on the WhaleMap (Johnson et al. 2021) internet site (https://whalemap.org/).

3.2.2 Archival Acoustic Data Analyses

DSZ

Right whale upcalls were detected in the archival acoustic record on 39 days of the 116 days surveyed (Fig. 5), but only 18 of those days had three or more calls and were subsequently scored by the analysts as having whales 'present'. Right whales were present in the archival record on 13 of 14 days that they were scored as definitely detected in real-time (true positive), and on five days when they were scored in real-time as either possibly being present or not detected (false negative). This translates into a false positive rate of 7% and a false negative rate of 5% over the deployment period (Tables 3 and 4). The number of upcalls on days when right whales were present ranged from three to 124. Despite the 21 days in the archival record when they were possibly present (i.e., there were fewer than three calls detected), only five of those occurred when slowdowns were not active or were not on days when real-time definite detections ended up triggering speed limit restrictions. This means that very few missed detections in real-time, or the treating of possible detections as unconfirmed presences of right whales, would translate into the potential for an increased risk to the whales.

Possible detections were reported on 30 days in real-time. Right whales were scored as absent in the archival record on 26 of these 30 days (Table 4). Right whales were scored as not detected in real-time on 72 days and were confirmed archivally as absent on all but one of these days.

Table 4. Summary of all detections of right whales for the DSZ glider in 2021, and percentages of detections that were True Positives, True Negatives, False Positives and False Negatives. A description of terms and calculations is provided in Table 3 and section 2.3 of the report, respectively.

	Archival Present:	Archival Absent:
Real-time Definite	13	1
Real-time Possible	4	26
Real-time Not Detected	1	71
	Rates (%):	
True Positive	93	
False Positive	7	
True Negative	95	
False Negative	5	

Cabot Strait

The Cabot Strait deployment presented challenges for reviewing the archival record. First, there were few days with right whale upcalls, and generally low upcall densities (Fig. 7). Second, there was an abundance of ship noise cluttering the record. Third, during late October, both right whales and humpback whales were sighted in the area by aerial surveillance. This is an issue because humpback whales can make similar sounds as right whales. Humpback whales were sighted on October 13th located ~3.5 nautical miles from the glider, and right whales were visually detected ~ 16 nautical miles from the glider on the same day. Right whales were again detected from the air on October 19th and October 26th (Fig. 9). It can be inferred from these sightings that both species were present in the area during the time period when right whale upcalls were recorded on the glider (Fig. 7).

Right whale upcalls were present on the archival acoustic record on six days of the survey (Fig. 7). All but one of these days occurred during the period of 14th – 23rd October, which encompassed the time period that they were sighted by the plane. On October 14th and October 20th, upcalls appeared in bouts of several calls produced at regular intervals. In particular, on October 20th, several bouts of 20 or more upcalls per bout were detected on the archival record. Although these calls sounded like right whales, upcalls are more typically made at irregular intervals. Additional expert advice was sought to determine if these bouts could be definitively attributed to right whales. The consensus in the acoustics community is that right whales can produce these bouts. However, humpback whales can also produce such calls in such patterns. So, following this study's conservative protocol, these calls were scored as unknown in the archival record and may have resulted in an undercounting of true right whale acoustic presence on these dates.

Therefore, this study's analysis confirmed right whale upcalls were found on the archival acoustic record on six days of the survey (Fig. 7), but only two of those days had three or more calls and were subsequently scored as per the protocol adopted in this surveillance program as having whales 'present' for the purposes of assessing detector performance. Right whales were scored as present in the archival record on one of the two days that they were scored as definitely detected in real-time (Table 5). On the second of these two days, only two upcalls were found on the archival record. Right whales were not present in the archival record on any of 13 days when they were scored as possibly being present in real-time. Right whales were scored as archivally present on only one of 93 days when they were scored as not detected in real-time. True and false positive rates were not calculated for this mission because they are not informative due to the small number of days when right whales (2) were scored as definitely present during the 107-day deployment.

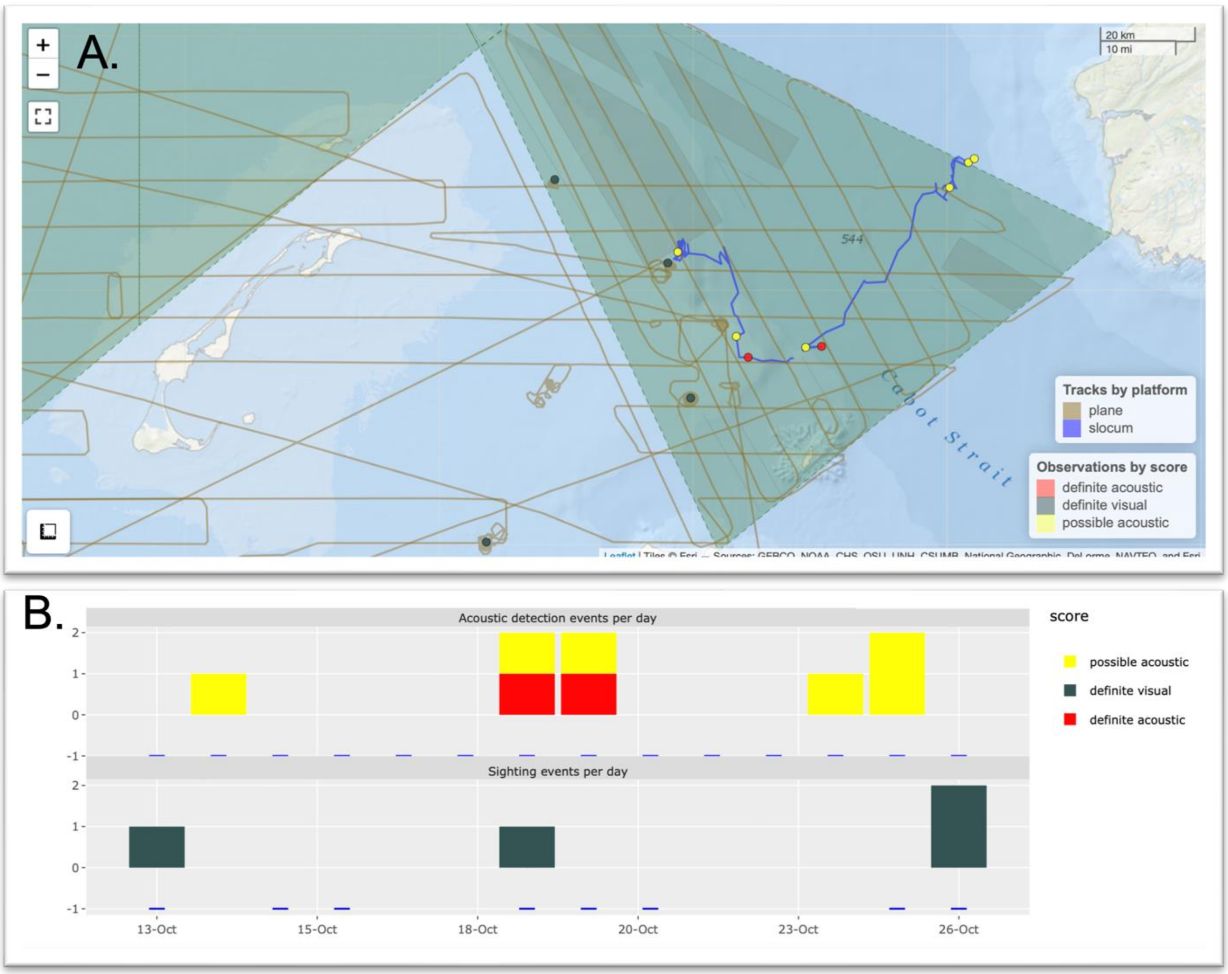

Figure 9. Right whale aerial and acoustic survey tracklines (A) and acoustic and visual detections (B) during 13-26 October, 2021. Map produced using open-access layers on the WhaleMap (Johnson et al. 2021) internet site (https://whalemap.org/).

Table 5. Summary of all detections of right whales for the Cabot Strait glider in 2021, and percentages of detections that were True Positives, True Negatives, False Positives and False Negatives. A description of terms and calculations is provided in Table 3 and section 2.3 of the report, respectively.

	Archival Present:	Archival Absent:
Real-time Definite	1	1
Real-time Possible	0	13
Real-time Not Detected	1	92
	Rates (%):	
True Positive	N/A	
False Positive	N/A	
True Negative	99	
False Negative	1	

4.0 SYSTEM PERFORMANCE AND OPERATIONS CONSIDERATIONS

4.1 System Performance

The gliders' flight performance and real-time detection system performed as intended during the deployments. 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. Like previous glider deployments (Davies et al. 2020, Davies et al. 2021), the gliders were able to consistently navigate well along their intended track lines. Importantly, the DSZ C glider did not enter the shipping lanes, meaning risk to the glider was minimized with this survey design. Outside of a software malfunction that required the DSZ glider to be retrieved for repairs and resulted in a short deployment hiatus, only once did the glider deviate from its typical progress along the transect, due to variable currents that resulted in an east-to-west transit taking 14 days rather than the average six. From October 9th-18th, the Cabot Strait glider encountered strong currents that prevented the completion of its AS transect and required pilot intervention.

In response to the Laurentian Channel glider detections, a speed limit in DSZ C was implemented for 62.1% of the survey period. The DSZ 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 two occasions during the survey, the glider was in this buffer zone when it made a right whale detection, causing a 10-knot speed limit to be implemented in both DSZ B and DSZ C.

These results indicate that the gliders are an effective monitoring method to support dynamic shipping management in DSZ C, as well as to monitor incoming/outgoing whales through the Cabot Strait. 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.

There were minimal right whale detections in the Cabot Strait even though incoming and outgoing whales moving to and from the Gulf of St. Lawrence pass through this area. This could be the result of several factors, including high noise levels in the Strait from vessel traffic degrading glider hydrophone performance, and/or low calling rates by whales during migration. A challenge for the monitoring program is the conservative approach that is taken for real-time monitoring, which aims to minimize false positives at the expense of false negatives. By requiring a minimum of three calls at least 10 dB above the background noise to be pitch-tracked in one 15-minute tally period to score a 'definite' detection, the program is under-sampling quieter calls and/or those that only occur once or twice. This is especially important to consider, given that travelling whales during migration may vocalize at lower rates than during other behavioural states across their ecological range (e.g., Davis et al. 2017). Therefore, it is uncertain whether real-time monitoring using the same protocols as in the DSZs will be effective for accurately monitoring whale movements through the Cabot Strait. However, with field studies, it is always risky to draw general conclusions from a single year of observation, as the environment and animal behavior may change considerably between years (Weatherhead, 1986). At least one more year of observations in the Cabot Strait using similar protocols to 2021 is recommended to reduce uncertainty and to better characterize patterns of whale calling during periods of migration.

4.2 Glider power requirements

Teledyne Webb Research recently implemented a hardware revision of their gliders. This involved changing the flight and data logging computers of the glider to a more modern but also more power-hungry system. All new gliders contain these new computers, and the updated glider model is referred to as the G3s, whereas the original model is referred to as the G3. The G3s used in this study demonstrated the higher demand for power compared to the older G3 unit. Exact power differences are difficult to calculate because two gliders need to perform under identical circumstances. However, the CEOTR glider group estimates that the G3s gliders consume 20-30% more power, which translates to a reduction of mission length by the same amount. The CEOTR glider group has brought these power consumption concerns to the manufacturer. They are aware of the issue and have been working on ways to reduce the G3s gliders' power consumption. The manufacturer has already presented one solution to reduce the power consumption of the Iridium modem by compressing the gliders' proprietary data files. By sending smaller compressed data files, gliders will spend less time powering their Iridium modem, thereby saving power. It is unclear how much power savings will be obtained by this method, but the CEOTR glider team intends to implement this feature.

Slocum gliders have buoyancy engines optimized for a given water depth. There are 1) shallow depth pumps that use steel pistons, and 2) deep-diving oil bladder pumps. Although glider engines can always operate in shallower waters than they are rated for, doing so increases energy consumption. To optimize battery usage, it is best to choose a buoyancy engine close to the average water depth encountered. For most of the Gulf of Saint Lawrence shipping channel, this depth is between 300 and 500 meters, however, there are shallow regions near the AS line of the Cabot Strait. For the 2021 sampling season, a 350 m buoyancy engine was chosen for both gliders, which provided good energy efficiency in all areas other than certain regions of the AS transit of the Cabot Strait. Transit through these shallower regions resulted in an approximately 10% increase in power consumption. Moving the AS transit line 1.5 nautical miles to the east would increase the average depth of the transect and increase the longevity of the mission.

4.3 Glider data backlog

The process of prolonging dives while the gliders are in the shipping lanes to protect them from collisions results in a backlog of data that needs to be transmitted afterwards. In 2021, occasionally a glider spent a longer than normal period submerged because it was under a shipping lane, resulting in larger than normal data records to transmit when it surfaced. As well, if there were faulty Iridium communications when the glider surfaced to transmit data, the glider could not send its complete set of backlogged data files in the short periods that the polar orbiting Iridium satellites were in range. These data backlogs in some circumstances slowed the movement of information from the glider to the science team. For the 2022 season, the CEOTR glider pilots plan to address this problem by altering the gliders' default file transfer settings and adjusting server-side scripting. This should remedy most backlogs in a timely fashion, although there could still be a backlog if problems occur with the Iridium satellite network.

During the 2020 monitoring season, there was a wide-scale Iridium outage, which prevented any real-time acoustic data transmissions over a period of days. During the 2021 monitoring season, this did not happen. However, there were times when the gliders' data transmission was interrupted due to problems with the Iridium satellite network. Faulty Iridium connections occasionally occur on most glider missions when the Iridium satellite orbit is low on the glider's horizon. This problem is usually infrequent. However, from October 13th through October 16th, it occurred more frequently and affected both of this project's gliders. The gliders were able to make successful connections during this time, but the connections were not stable and would usually disconnect before all data could be sent. This created a backlog of data that was cleared once Iridium communications stabilized. Despite reaching out to the Iridium service provider, the exact cause of these Iridium communication instabilities remains unknown. However, they are suspected to be related to an unlucky placement of satellites relative to both gliders. Fortunately, this problem did not pose a serious challenge to the success of the missions. The practical consequences of poor or interrupted Iridium communications are a delay in the transmission of right whale detections to the management system, undermining the objective of rapid reporting of whale presence so timely measures can be implemented. It could be several hours before the next satellite is in range, depending on the satellite orbits, so leaving the glider on the surface to wait to make contact is not recommended because it increases the risk of ships colliding with the glider and reduces the area covered and monitoring time for right whales. However, as noted above, the glider team believes a solution has been found that will resolve most instances of this problem.

4.4 Plan for persistent currents

Gliders can control their vertical velocity through the water column by altering their density via a buoyancy pump. Their horizontal speed is therefore based on the gliders' vertical velocity, the angle at which they glide through the water, the magnitude and direction of water currents, and time spent on the surface. To collect high quality acoustic audio data by reducing flow noise from the glider, a maximum vertical velocity was established at 15 cm/s. This inherently puts an upper limit on the gliders' horizontal speed. The gliders' horizontal velocity could be temporarily increased by approximately 5% if near real-time data transfer is paused, however, any gains in distance would be lost once the glider surfaces for longer periods of time to upload the backlog of data at a later date.

When strong opposing currents are present, such as during the northern section of the AS transit in the Cabot Strait from October 9^{th} to 18^{th}, a choice must be made on the best strategy to make forward progress. If the current is expected to be transient, then waiting for it to dissipate is an option. Alternatively, an effort can be made to move perpendicular to the current and subsequently re-attempt the intended heading from a different starting point. These methods were both tried during the 2021 mission with no success. Eventually, the glider was programmed to turn around and perform a CS transit instead of finishing the AS transit. In future years, a plan will be laid out in advance regarding how long to wait for such currents to subside, the amount of effort to be devoted to attempting to move out of the currents, and when to resign ourselves to the fact the current wins and turn around.

4.5 Damage during recovery

During the recovery of the DSZ glider on November 9^{th}, the rudder and antennae system were damaged by colliding with the recovery vessel. This deformed the gliders fin, which required replacement. This emphasizes the need to have contingency funds set aside to assist with the replacement of parts or repair of the glider due to such accidents. The deployment and recovery of gliders is a period of significant risk and, despite a boat crew with lots of experience and careful attention to operations, accidents can happen. Late in the year there are fewer options for chartering recovery vessels because much of the commercial fleet is hauled out of the water for winter. The ones that remain are usually large with long distances off the side or stern railing to the water, which is less ideal for glider recoveries. In the future, if the same vessel is chartered, its configuration will be changed to ensure a safer recovery for both the crew and glider.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Glider operations in 2021 to support right whale monitoring efforts in the Gulf of St. Lawrence DSZ C and in the voluntary speed reduction zone in the Cabot Strait successfully detected the presence of right whales and four other baleen whale species. Right whale detections were rapidly reported to managers who used the information to implement necessary protection measures. Based on glider detections in DSZ C, mandatory vessel speed reductions were implemented for 62.1 % of the 116-day glider mission. Aerial flights over DSZ C on 50 days during the period the glider was monitoring did not sight right whales. Thus PAM equipped gliders are clearly a useful tool supporting the Government of Canada's multifaceted protection efforts for this endangered species in the Gulf of St. Lawrence. No fatalities of right whales were reported in the Gulf of St. Lawrence in 2021.

A second glider deployed in 2021 to the Cabot Strait also successfully detected right whale calls in this area, but at a much lower rate than anticipated. The Strait is believed to be the primary migration corridor for right whales to seasonally enter and exit the Gulf of St. Lawrence and why the whales did not call in this area is the subject of current research. The lack of calls may indicate that the whales reduce or in some cases stop calling while they are migrating.

The primary challenges to glider operations in 2021 were water currents, satellite communications, and technology faults. One glider also suffered damage during its recovery at the end of the season. Regarding currents, while they sometimes modified course paths planned for the gliders in 2021, their effects were manageable. As the glider technical team gains experience with and knowledge of the conditions in the Gulf, future mission plans will be designed so that the missions will be minimally impacted by currents. Satellite communication issues are beyond the control of the project participants, outside of complaining about poor service, and must be left to the Iridium network to resolve. The Iridium network is the only communications link able to connect to the project gliders. The communication issues the project faced in 2021 affected many additional Iridium customers, hence it is in the company's best interests to fix these issues. With regards to technology faults in the gliders, these are complex machines and things will occasionally fail. We had a single failure due to a software issue in 2021 that required a glider to be retrieved and repaired. This was rapidly accomplished, enabled by the skill and technical competence of the glider team. This team will be in place for the 2022 season, and a stand-by glider will be ready to replace any glider that has a technical issue.

Recommendations for the future

Based on the knowledge gained by the project team, the following recommendations are proposed for subsequent deployment year(s):

- Continue incorporating the lessons learned from the previous years' operations into plans for unanticipated events in future years. For 2022, set limits on how long to wait for unexpected currents that are encountered to subside and the amount of effort to be devoted to attempting to move out of such currents before changing the glider's flight plan.
- To avoid recovery and launch damage to the gliders, especially in the spring and autumn when the weather is less favorable, the field team should work with vessels and crew known to be experienced with safely deploying and retrieving ocean instrumentation and with vessels whose configurations can be modified as needed to reduce the risk of damage to the gliders.
- Continue glider monitoring for right whale calls for a second year in the Cabot Strait to ensure that the observations from the first year are representative of the call patterns that can be expected from right whales in this area and continue as possible to support research into when and why whales do and do not call.
- If Transport Canada judges that the glider program is a cost-effective and valuable tool to detect and protect right whales and should be expanded, begin discussions regarding how funding to expand the glider fleet could be acquired.

6.0 REFERENCES

Baumgartner, M. F., and Mussoline, S. E. (2011). A generalized baleen whale call detection and classification system. J,. Acoust. Soc. Am. 129, 2889–2902. doi: 10.1121/1.3562166

Baumgartner, M. F., Fratantoni, D. M., Hurst, T. P., Brown, M. W., Cole, T., Van Parijs, S. M., et al. (2013). Real-time reporting of baleen whale passive acoustic detections from ocean gliders. J. Acoust. Soc. Am. 134, 1814–1823. doi: 10.1121/1.4816406

Baumgartner, M. F., Bonnell, J., Van Parijs, S. M., Corkeron, P. J., Hotchkin, C., Ball, K., et al. (2019). Persistent near real-time passive acoustic monitoring for baleen whales from a moored buoy: system description and evaluation. Methods Ecol. Evol. 10, 1476–1489. doi: 10.1111/2041-210X.13244

Baumgartner, M.F., Bonnell, J., Corkeron, P.J., van Parijs, S.M., Hotchkin, C., Hodges, B.A., Thornton, J.B., Mensi, B.L., and Bruner, S.M. 2020. Slocum gliders provide accurate real-time estimates of baleen whale presence from human reviewed passive acoustic detection information. Frontiers in Marine Science 7(100): 1-12

Crewe, M., Brown, M. W., Corkeron, P. J., Hamilton, P. K., Ramp, C., Ratelle, S., Vanderlaan, A.S.M. and Cole, T. V. N. 2021. In plane sight: a mark-recapture analysis of North Atlantic right whales in the Gulf of St. Lawrence. Endangered Species Research 46:227-251

Davis, G. et al. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Scientific Reports 7(13560): 1-12

Davis, R., Comeau, A, L'Orsa, S., van der Meer, J., Covey, B. Pye, J. and Whoriskey F. 2018. Lessons learned in developing a Canadian operational glider fleet. Mar. Tech. Soc. J. 52(3):13-18.

Davies, K.T.A. 2020. Near real-time passive acoustic monitoring of North Atlantic right whales (*Eubalaena glacialis*) using profiling electric gliders in the Honguedo Strait, Gulf of St. Lawrence. Final Report to the Transport Canada Innovation Centre.

Davies, K.T.A. 2021. 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. Final Report to the Transport Canada Innovation Centre.

Durette-Morin, D., Davies, K.T.A., Johnson, H., Moors-Murphy, H., Martin, B., and Taggart, C. 2019. Passive acoustic monitoring predicts daily variation in North Atlantic right whale presence and relative abundance in Roseway Basin, Canada. Marine Mammal Science 35(4): 1280-1303

Durette-Morin, D. 2021. Measuring the distribution of North Atlantic right whales (*Eubalaena glacialis*) across multiple scales from their vocalizations: applications for ecology and management. M.Sc. thesis, Dalhousie University, Halifax, Canada.

Johnson, H., Morrison, D. and Taggart, C. 2021. WhaleMap: a tool to collate and display whale survey results in near real-time. Journal of Open Source Software 6(62), 3094, 4p. https://doi.org/10.21105/joss.03094.

Johnson, M., and Hurst, T. (2007). “The DMON: an open-hardware/open-software passive acoustic detector,” in 3rd International Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics, Boston, MA.

Schofield, O., Kohut, J., Aragon, D., Creed, L., Graver, J., Haldeman, C., et al. (2007). Slocum gliders: robust and ready. J. Field Rob. 24, 473–485. doi: 10.1002/rob. 20200

Weatherhead, P. J, 1986. How unusual are unusual events? American Naturalist 128: 150-154.