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STANDARDISED PROTOCOLS FOR VESSEL-BASED MARINE BIRD SURVEYS ON CANADA'S PACIFIC COAST

Canada

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ABSTRACT

Canada's Pacific coast hosts over 160 species of marine birds, with tens of millions of individuals breeding, overwintering, and migrating along the coast, in addition to resident populations. Marine birds, defined here as seabirds, marine waterfowl, shorebirds, and marine raptors, represent species that are reliant on marine ecosystems. As higher trophic level consumers, marine birds play fundamental roles in marine ecosystems. Influenced by natural environmental dynamics in marine ecosystems, marine birds also respond to anthropogenic stressors, with many species in the North Pacific Ocean exhibiting significant declines in recent decades. In order to effectively conserve marine birds, accurate, up-to-date information regarding their distribution and abundance is a fundamental knowledge component. At-sea vessel-based marine bird surveys represent one method used to obtain such information, acknowledging that vessel-based at-sea surveys are not appropriate for all marine bird species. Since the early 1980's, Environment and Climate Change Canada has undertaken marine bird surveys, largely using ships-of-opportunity and a strip transect survey method on Canada's Pacific coast. The strip transect survey method is a commonly used technique of surveying marine birds, in part due to its simplicity and flexibility, and has been a common approach on Canada's Pacific coast for decades. More recently, line transect surveys of marine bird communities has become increasingly prevalent amongst programs that require robust, quantitative information, including population estimates. The objectives of this report are to provide standardised protocols for vessel-based strip transect and line transect methods as well as guidance for the selection of appropriate methodology. We also provide a brief overview of alternative, non-vessel based marine bird survey techniques, which may be more a more appropriate choice based on program objectives. Standardising marine bird data collections will allow for greater data integration, provide a more complete and accurate understanding of marine bird communities on Canada's Pacific coast, and, ultimately, support more effective conservation and management approaches.

TABLE OF CONTENTS

Acknowledgements iv
Abstract 1
Table of contents 2
List of Figures 3
List of Tables 3
1 Introduction to Marine Bird Surveys 4
1.1 Introduction and objectives 4
1.2 Vessel-based marine bird surveys 5
1.3 Vessel-based marine bird surveys on Canada's Pacific coast 6
1.4 Selecting survey methodology 6
1.5 Other marine bird survey methods 9
1.5.1 Alternative survey methods 9
1.5.2 Aerial surveys - occupied aircraft 9
1.5.3 Aerial surveys - unoccupied aircraft systems 10
1.5.4 Shore-based surveys 11
2 Line Transect Protocol 11
2.1 Introduction to line transects 11
2.2 Study design 14
2.3 Requirements for observing 15
2.4 Methods 15
2.4.1 Prior to surveys 15
2.4.2 Effort 16
2.4.3 Survey protocol 17
2.4.4 Environmental information 22
2.4.5 Other taxa 23
2.4.6 Data recording 24
2.5 Data Analyses 24
3 Strip Transect Protocol 24
3.1 Introducing strip transects 24
3.2 Study design 25
3.3 Requirements for observing 25
3.4 Methods 26
3.4.1 Prior to surveys 26
3.4.2 Effort 27
3.4.3 Survey protocol 27
3.4.4 Environmental information 30
3.4.5 Other taxa 30
3.4.6 Data recording 31
3.5 Data Analyses 31
References 32
Appendix 1. Equipment list for conducting marine bird surveys 41
Appendix 2. Beaufort scale, true wind speed, and sea state 42
Appendix 3. Manual calculations for distance estimation 43
Appendix 4. Method for counting large numbers of flocking birds 44
Appendix 5. Detecting birds when starting a line transect 45
Appendix 6. Example strip transect survey data manual data entry form 47

LIST OF FIGURES

Figure 1. (a) Graphical representation of line transect surveys with a single observer; (b) distance sampling detection function.

Figure 2. Graphical representation of a line transect survey from a moving platform.

Figure 3. Graphical representation of strip transect surveys from a moving platform.

Figure 4. Distance estimation using a distance gauge constructed from a transparent plastic ruler.

Figure 5. Flock of Snow Geese (*Anser caerulescens*) in flight.

Figure 6. Graphical representation of the beginning of a line transect.

LIST OF TABLES

Table 1. Considerations for vessel-based surveys of marine birds.

Table 2. Beaufort scale descriptors.

Table 3. Environmental and survey related variables recorded by observers undertaking marine bird line transect surveys.

Table 4. CWS sightability scale descriptors.

Table 5. Environmental and survey related variables recorded by observers undertaking marine bird strip transect surveys.

1 INTRODUCTION TO MARINE BIRD SURVEYS

1.1 Introduction and objectives

Canada's Pacific coast supports tens of millions of marine birds (defined here as species that are reliant on marine ecosystems, including seabirds, marine waterfowl, shorebirds, and marine raptors) each year, representing globally, nationally, and regionally significant numbers. Representing a portion of the Pacific Flyway, which stretches from Tierra del Fuego to the high Arctic, millions of marine birds migrate along the coast each year. Millions of seabirds also breed along the British Columbian (BC) coast, with notable colonies located on Triangle Island, along the archipelago of Haida Gwaii, and elsewhere. The North Pacific Current, flowing eastward across the ocean, bifurcates against the British Columbian (BC) coast to form the northward flowing Alaska Current, and the highly productive southward flowing California Current. The California Current, which includes coastal waters along BC's southern coastline, ranks among the world's most productive upwelling ecosystems (Pauly and Christensen 1995), and supports a diversity of taxa, including marine birds. As an archipelago of thousands of islands, fjords, several shallow seas (e.g., Hecate Strait), the more sheltered, inland Salish Sea, and a variable continental shelf that stretches offshore, the coast provides a rich diversity of habitats for marine birds.

As upper trophic level consumers, marine birds play fundamental ecological roles in marine ecosystems (e.g., Tavares et al. 2019) and can act as sentinels for shifts in ocean conditions (Moore and Kuletz 2019). Despite their importance, many species are exhibiting declines in recent decades (Croxall et al. 2012; Paleczny et al. 2015), including on Canada's Pacific coast (e.g., Bower 2009; Drever et al. 2021). In order to conserve marine birds, accurate, up-to-date information regarding their distribution and abundance represents a fundamental knowledge component. At-sea vessel-based marine bird surveys represents one approach, among others, to obtain distribution and abundance information for marine birds at-sea, acknowledging that vessel-based surveys are not appropriate for all marine bird species across the diversity of habitats in which they occur.

The objectives of this report are to: (1) provide standardised protocols for vessel-based line transect and strip transect survey methods of marine birds at sea; (2) provide guidance for the selection of an appropriate survey method, and; (3) support marine bird data collection becoming more comparable and to allow for greater data integration amongst survey programs on Canada's Pacific coast. These methods are used by Environment and Climate Change Canada (ECCC), Pacific Region to: (1) provide baseline information regarding the distributions and abundances of marine birds at-sea; (2) detect changes in marine bird distributions and abundances at-sea; (3) understand marine bird-habitat associations, and; (4) inform conservation and management efforts, such as increasing understanding of the risks posed by fisheries, marine traffic, and other anthropogenic activities on marine birds (e.g., Kenyon et al. 2009; Fox et al. 2017; Bertram et al. 2021; Fox et al. 2021).

Two marine bird vessel-based survey protocols are described in this report. A line transect protocol (Section 2; Buckland et al. 2001), largely modified from Raphael et al. (2007) and Fox et al. (2017), has been recently developed by ECCC Pacific Region. Line transect surveys can be used to produce quantitative marine bird distribution and abundance information, calculate abundance estimates, and/or generate predictive models of bird distributions and abundances (e.g., Ronconi and Burger 2009; Fox et al. 2017). A strip transect survey protocol, used by ECCC Pacific Region since the 1980s, is detailed in Section 3. ECCC's Pacific Region strip transect surveys have been primarily conducted from ships-of-opportunity and support the collection of low-cost, long-term information regarding the distributions and relative abundances of marine birds at-sea.

1.2 **Vessel-based marine bird surveys**

The use of vessels as platforms for observers to document and describe birds at-sea has been common since the 19th century (Brown 1980). Some of the first modern, systematic surveys of birds from vessels were conducted in the early 20th century, describing species distributions in the Atlantic and Pacific Oceans (e.g., Wynne-Edwards 1935, Murphy 1936). Although statistical and technological innovations in the past century have led to changes in survey techniques, vessel-based surveys remain among the most widely used methods for describing the distribution and abundance of marine birds at sea (Balance 2007). The widespread availability, relative autonomy, and flexible operating tolerances of vessels make them a useful platform for at-sea marine bird surveys on Canada's Pacific coast.

Ships-of-opportunity are a cost-effective alternative to dedicated vessels for marine bird research and monitoring programs. Although control over transect line placement is relinquished, replication may be achieved by surveying along regularly travelled routes. For example, Canadian Coast Guard vessels travel the same route while conducting oceanographic research (e.g., Kenyon et al. 2009), or ferry vessels travel similar routes between ports (e.g., Canadian Wildlife Service, *unpublished data*; Sahri et al. 2020). Surveys from ships-of-opportunity can provide valuable information about the distribution, abundance, and seasonal and inter-annual occurrences of marine birds, particularly when financial resourcing is limited, as is often the case for many marine bird survey programs. Further, the often low to negligible cost of undertaking marine bird surveys aboard ships-of-opportunity tends to result in substantially more data collected than can be achieved using dedicated survey vessels.

The choice of survey vessel may also have consequences for survey outcomes. Larger vessels are more costly to operate but typically have higher observation platforms, and which offer more stable observation platforms in inclement weather or with large ground swells. They are also often more autonomous than smaller vessels, capable of working in remote areas for longer periods without resupply. However, when surveying, larger vessels being more visible may cause some species to flush at further distances, making detection more difficult (*reviewed in* Lima et al. 2015). Similarly, vessel size, and weather conditions will influence detectability of smaller or cryptic species during surveys (Ronconi and Burger 2009). While larger vessels are more stable in rough waters than smaller vessels, large vessels with deeper draughts cannot survey in shallow waters near shore. Decisions regarding the choice of survey vessel will therefore depend on the survey area, time of year, target species, resourcing, and other considerations.

1.3 Vessel-based marine bird surveys on Canada's Pacific coast

At-sea marine bird surveys on Canada's Pacific coast have been undertaken since at least the mid-1900's (Martin and Myers 1969; Vermeer et al. 1983 *and references therein*). The atlas of marine birds on Canada's Pacific coast (Vermeer et al. 1983) compiled species composition and densities but mainly focused on the distribution of inshore waters, with little detail for pelagic (i.e., offshore) species. With a need to understand marine bird species distributions and abundances in Canadian waters, Environment Canada (now Environment and Climate Change Canada) initiated opportunistic surveys off BC's coast in 1981 to understand the spatiotemporal composition of marine birds and provide baseline data for assessing environmental impacts (Morgan et al. 1991). Early survey areas, including Hecate Strait, Queen Charlotte Sound, Dixon Entrance, and the west coast of Vancouver Island, out to and beyond Canada's Pacific Exclusive Economic Zone (EEZ), were summarized in Morgan et al. (1991). Surveys aboard Canadian federal government and commercial ships-of-opportunity have continued until present to document the seasonal distributions and densities of marine birds and extend throughout and beyond Canada's EEZ. Updated information is available in Kenyon et al. (2009). As surveys were opportunistic and effort was not evenly distributed, the data are unsuitable for estimating population size or temporal abundance trends (Kenyon et al. 2009) but have been invaluable for the documentation of marine bird species composition, distribution, seasonal occurrence, bird-habitat associations, and relative abundance.

The first large-scale, systematic vessel-based marine bird survey on BC's coast was initiated in 2005. Raincoast Conservation Foundation began a four-year vessel-based systematic line transect survey on BC's north coast to document the distribution and abundance of marine birds (Fox et al. 2017). Surveys were conducted in the Queen Charlotte Basin from Dixon Entrance to Queen Charlotte Strait in all seasons, except winter. Predictive models of marine bird densities were developed and subsequently combined to generate seasonal and overall predictions of areas important to marine birds (Fox et al. 2017).

Many other at-sea surveys have been completed in BC using a variety of survey methods: Kitimat Arm, Douglas Channel, and along the coastal islands, from Caamaño Sound to Porcher Island, 2005-2009 (d'Entremont 2010); the 'great circle route' in the North Pacific Ocean (i.e., southern BC to Japan, through the Gulf of Alaska, southern Bering Sea, and western North Pacific, 2000-07, Batten et al. 2006; Sydeman et al. 2010); southern Gulf Islands, 2008-09 (Davidson et al. 2010); southern Howe Sound, 2014-15 (Butler et al. 2018); Fraser River Estuary, 2016-2017 (Butler et al. 2018); west coast Vancouver Island, 1999-present (Parks Canada, unpublished data); Queen Charlotte Strait, 2020-2021 (Gaston et al. 2020), and others.

1.4 Selecting survey methodology

Two methods dominate mainstream approaches for vessel-based surveys of marine birds: line transect and strip transect surveys. Line transect distance sampling (Buckland et al. 1993, 2001, 2004, 2015) is more accurate, but also a more resource intensive survey method than strip transect surveying, due in part to observer training requirements (Ronconi and Burger 2009). The strip transect method is a popular and straightforward approach for conducting at-sea marine bird surveys, particularly if resources are limited or unpredictable, trained observer availability is limited, and/or if observers are infrequently travelling on different ships-of-opportunity without an opportunity for retraining (e.g., Hyrenbach et al. 2007). Choosing an appropriate methodology when conducting line transect vessel-based marine bird surveys depends on many factors. Study objective(s), study area and species, resourcing, and historical precedent can all influence decision making. Common factors to consider when choosing a methodology for vessel-based marine bird surveys are summarized in Table 1, with considerations outlined below.

If study objectives require robust, quantitative density estimates, population-level abundance estimates for a study area (e.g., Goyert et al. 2016), and/or quantitative trend analysis (e.g., Buckland et al. 2004), line transect surveys should be considered. While predictive density and distribution modelling can be achieved using strip transect survey information (e.g., Oppel et al. 2012), often quantitative density estimates coupled with predictive modelling are key project objectives that require line transect data (e.g., Fox et al. 2017). Strip transect survey data are considered to generate 'relative' estimates of abundance, and important limits on the use of the data for quantitative analyses should be considered. Robust study area population estimates cannot be generated using strip transect data (Ronconi and Burger 2009). Trend analysis using strip transect information will be reliant on relative measures of abundance, and predictive models should be developed with caution, particularly with regard to their application.

Study area and species will also influence methodology choice. If surveys occur in variable weather conditions, or involve smaller or more cryptic species, both of which frequently occur in the North Pacific Ocean, line transect surveys may be a more appropriate method as the density estimates produced account for undetected birds (Ronconi and Burger 2009). When conducting strip transect surveys in poor weather it is possible to reduce the strip width to try and ensure that all birds are detected; however reducing strip width increases the variance of abundance estimates, especially with smaller sample sizes (Burnham et al. 1985; Clark 2016). For surveys that encounter mixed flocks in high densities, strip transects may be a more efficient method of surveying, as the additional data collected for line transect sightings may lead to some birds being missed (Hyrenbach et al. 2007). This difference can be reduced with highly trained observers collecting data via audio recordings, which is a more efficient collection method than manual data entry. Thus, with appropriate technique, line transect surveys can be an effective method for surveying mixed, high density flocks.

Vessel-based surveys typically require significant financial resources, and thus funding is commonly one of the most significant determinants of survey methodology. Regardless of the method used, systematic surveys from chartered vessels are typically more expensive to conduct than non-systematic surveys on ships-of-opportunity. If sufficient resources are available to conduct a large-scale vessel-based systematic study, adoption of a line transect methodology is recommended. This is a more quantitative method of surveying marine bird populations than strip transect approaches, producing more statistically robust data if assumptions are met

(Ronconi and Burger 2009).

Compatibility with historic data is also an important point of consideration for long-term monitoring projects. When calculating trends from combined data sets, methodological differences can introduce artefacts that obscure true population changes. Strip transect approaches were developed in the 1980's and widely adopted by marine bird monitoring programs (Tasker et al. 1984). Line transect distance sampling was developed later (Buckland et al. 1993), although adoption of line transect methods for marine bird vessel-based surveys remains mixed on Canada's Pacific coast and surrounding regions. Strip transect and line transect data can be combined using density estimates generated along transect segments (e.g., Fox et al. 2021), using the perpendicular distance recorded as part of the line transect data to allow for strip width density estimation (Ronconi and Burger 2009), or other approaches (e.g., Miller et al. 2021). However, care is required. Decisions to combine data collected using disparate approaches are commonly made when insufficient, high-quality information is available, as is frequently the case for at-sea marine bird monitoring programs.

Table 1. Common considerations for vessel-based surveys of marine birds.

Factor	**Strip Transect**	**Line Transect**
Resourcing	Less resource intensive [a]	More resource intensive [a]
Compatible vessels	Ships-of-opportunity [b] or dedicated vessels [c]	Ships-of-opportunity [d] or dedicated vessels [a]
Survey design	Systematic or opportunistic [b,e]	Systematic [f,g] or opportunistic [d,g]
Observers required	One-sided, single observer or two-sided, with two observers	Two-sided, with two observers recommended; one-sided, single observer possible
Training required	Less training to become proficient [a]	More training to become proficient [a]
Strip width	Strip generally ≤ 300 m in width [b,e]	Variable. Area can be greater or less than 300 m using the estimated detection function [g]
Detection assumption	All birds within the strip are detected [b]	All birds are detected on the transect line (i.e., g(0) = 1) [g]
Study Objectives	Relative estimates density, indices of abundance, and/or predictive modelling of density and distribution	Quantitative density estimates, population-level abundance estimates, and/or predictive modelling of density and distribution

[a] e.g., Ronconi and Burger 2009. [b] e.g., Hyrenbach et al. 2007. [c] e.g., Haney et al. 2019. [d] e.g., Gjerdrum et al. 2012. [e] e.g., Kenyon et al. 2009. [f] e.g., Fox et al. 2017. [g] Buckland et al. 2001.

1.5 **Other marine bird survey methods**

1.5.1 Alternative survey methods

Although vessel-based methods are widely used for surveying marine birds, alternative survey methods may be more suitable depending on the scientific objectives of the program in question. Here, we provide a brief overview of methods that may be considered, in addition to vessel-based surveys, for gathering information on the distribution and abundance of marine birds at sea. Typically, resource and time constraints are among the most significant obstacles when designing marine bird surveys. Where feasible, aerial or shore-based methods may offer efficiencies that are not possible with vessel-based surveys. Despite this, the scale and relative inaccessibility of much of Canada's Pacific coast, coupled with often extreme weather conditions, mean that for many areas and seasons, vessel-based surveys remain the most viable method for conducting at-sea marine bird surveys at present. However, emergent technology such as Unoccupied Aircraft Systems (UAS) commonly referred to as "drones", unmanned aerial vehicles (UAV), and coupling aerial surveys with high resolution digital photography and Machine Learning species identification, may provide promising and potentially less expensive alternatives to vessel-based surveys in the future.

1.5.2 Aerial surveys - occupied aircraft

Aerial surveys were adopted as a method of surveying marine birds in the 1970's and have become more widely used in subsequent decades (Briggs et al. 1985; Ainley et al. 2012). They are often a cost-effective way to quantify marine birds and evaluate distribution and abundance (Buckland et al. 2012). Benefits of aerial surveys are that the platform can quickly reach remote areas and survey expansive marine environments, offering cost-saving and logistical benefits. However, aerial surveys are often restricted from operating in weather conditions commonly encountered on the BC coast (Colefax et al. 2018), and there are known challenges with respect to the detection and identification of some species (Fifield et al. 2016; Kemper et al. 2016).

Occupied aircraft, such as planes and helicopters, are used to survey with either trained visual observers or more recently, digital camera arrays (Buckland et al. 2012; Kemper et al. 2016; Colefax et al. 2018; Žydelis et al. 2019; Garcia-Garin et al. 2020). Planes are comparatively cost- and time-effective compared to vessel-based surveys (Kemper et al. 2016), and cost-effective compared to helicopters if covering a large area (Buckley and Buckley 2000). Logistically, helicopters may not be as practical as planes or ships for reaching remote locations on the BC coast, and the high operational cost can be prohibitive to survey very large areas (Fleming and Tracey 2008), though they are a feasible and nimble platform for surveys close to shore. In 2022, helicopter surveys that targeted shorebirds and waterfowl in the intertidal and immediate nearshore were successfully piloted on the BC coast by CWS (Flemming and Ross, *unpublished data*) using a strip transect approach developed on Canada's Atlantic coast for Purple Sandpiper (*Calidris maritima*) and Harlequin Duck (*Histrionicus histrionicus*; Gutowsky et al. 2019).

Aircraft surveys may provide a more accurate estimate of species that are attracted to or repelled from vessels (Tasker et al. 1984; Spear et al. 2004; Fifield et al. 2016; Žydelis et al. 2019), yet may disturb and underestimate more sensitive species (Chilvers et al. 2015; Kemper et al. 2016). To identify species, occupied aircraft must be flown at relatively low altitudes (e.g., <100 m) and inherently at fast speeds (e.g., 250 km/h for planes and 170 km/h for helicopters), which may pose safety risks for occupants (Kemper et al. 2016; Verfuss et al. 2019; Žydelis et al. 2019). Compared to the substantially slower survey speeds of vessels, and even at low altitudes, aerial surveys likely result in poorer detection and identification of smaller, more cryptic species, species that are difficult to distinguish, or species within large aggregations of birds (Fifield et al. 2016; Kemper et al. 2016).

The logistical and staffing costs associated with conducting aerial surveys are currently similar for manual (i.e., occupied) and digital observations (Garcia-Garin et al. 2020). Manual in-flight data collection produces immediate results; however, more staff are usually needed to conduct these surveys than digital surveys (Chabot and Frances 2016). With digital surveys, fewer staff are needed in-flight; however reviewers are needed to analyse the resulting images (Buckland et al. 2012; Drever et al. 2015; Chabot and Francis 2016; Boudaoud et al. 2019). The benefit of digital observation techniques is that photographs can be archived and reanalysed if needed (Chilvers et al. 2015; Chabot and Francis 2016; Žydelis et al. 2019; Garcia-Garin et al. 2020). With the development of higher resolution cameras, detection of smaller or more cryptic species with digital methods may actually surpass that of manual observers leading to more accurate surveys (Buckland et al. 2012; Chabot and Francis 2016). With the advent of machine learning techniques and efficient algorithms being developed, automated reviews of digital surveys will likely reduce the cost of analysing digital aerial survey data (Boudaoud et al. 2019; Garcia-Garin et al. 2020).

1.5.3 Aerial surveys - unoccupied aircraft systems

With advances in imaging and analysis technologies, digital surveying of marine birds from aircraft without observers or from UAS are increasingly being used as an alternative approach for at-sea surveys (Chabot and Francis 2015; Colefax et al. 2018; Žydelis et al. 2019; Garcia-Garin et al. 2020). Currently, UAS are uncommonly used for surveying marine birds at sea, however they may provide feasible, cost-effective platforms for surveying marine birds in the future. UAS that can follow transect lines with minimal operator oversight are particularly suited for data collection in the open ocean (Verfuss et al. 2019). Autonomous flight using autopilot along transects might increase spatial sampling precision for optimal data collection (Johnston 2019; McClelland et al. 2016).

UAS fall into three main types; multirotor, fixed-wing, and transitional (combined rotors and fixed-wing; Johnston 2019). Multirotors are often used for nearshore regions due to range limitations (Johnson 2019). Multirotor UAS may be best suited for at-sea launches, due to their small lift-off area required, but may also require a boat-mode calibration sequence to operate properly (Johnson 2019). At-sea surveys from vessels may limit the size and type of UAS, thus limit the payload and range capabilities (Koski et al. 2010). Fixed-wing UAS generally obtain better flight efficiency than multirotors but are more difficult to launch and land (Colefax et al. 2018; Johnston 2019). Transitional UAS have the launch and land abilities of multirotors and the efficiency of fixed-wings and may be best-suited for large-scale marine surveys (Johnston 2019).

With many advantages over occupied aircraft, such as increased safety for personnel, there are still a number of challenges related to using UAS to survey marine birds at-sea. These include cost, range, weather-related operating limits, data analysis, logistical and technological limitations, wildlife disturbance, and perhaps most importantly, permitting and airspace restrictions, especially for long-range autonomous UAS (Koski et al. 2010; Drever et al. 2015; Vas et al. 2015; McClelland et al. 2016; Colefax et al. 2018).

1.5.4 Shore-based surveys

Shore-based surveys are conducted from land, from either stationary positions or along sections of coastline, covering nearshore marine areas within visible distances of land. Common approaches to shore-based surveys include fixed-distance, grid-based, and distance sampling from stationary positions or non-stationary transects (e.g., Crewe et al. 2012; Waggitt et al. 2014; Ward et al. 2015). Examples of stationary counts using a distance sampling method is detailed by Gjerdrum et al. (2012), a fixed-distances method by Wilhelm and Boyne (2006), and reviewed by Ronconi et al. (2015). In areas where the shoreline is accessible, shore-based surveys are an inexpensive and often logistically easier method to count nearshore marine birds than vessel- or aerial-based surveys. However, shore-based survey programs are generally limited to readily accessible coastlines in BC. Shore-based surveys can support the collection of long-term data sets for nearshore waters and/or supplement vessel- or aerial-based research programs; and, can be readily driven by community members, offering opportunities for collaboration, partnership, and engagement. Community science programs may provide an opportunity to apply rigorous models to estimate population indices and assess trends for nearshore marine birds over large areas in a very cost-effective manner (Crewe et al. 2012; Ward et al. 2015). For the areas of the BC where shore-based surveys can feasibly be conducted, these programs may provide invaluable information regarding marine birds in the nearshore. However, existing programs are in areas with relatively easy access to coastal survey sites; much of Canada’s Pacific coast is difficult to access and not well-suited to such programs.

2 LINE TRANSECT PROTOCOL

2.1 **Introduction to line transects**

Distance sampling is a widely applied group of methods, including line and point transect sampling, used to estimate wildlife density or abundance (Buckland et al. 2001). Line transect methods can achieve accurate estimations of density without recording every animal within the survey area (Figure 1; Buckland et al. 2001). Increasingly, line transect methods have been adopted by marine bird survey programs due to the accuracy of the quantitative estimates of density (e.g., Camphuysen et al. 2004; Gjerdrum et al. 2012; Fox et al. 2017) and population-level abundance (e.g., Goyert et al. 2016) that it can produce, which are fundamental data contributions that inform evidence-based management and conservation decisions (e.g., Fox et al. 2016).

When conducting line transects, perpendicular distance from a detected bird to the transect line is recorded for each observation (Figure 1a). Perpendicular distance (*d*) can be calculated as $d = r$ x $\sin \vartheta$ using trained observer estimations of radial distance to the detected sighting (*r*) and measured angle of detection (ϑ) (Buckland et al. 2001). Alternatively, trained observers may directly estimate perpendicular distance from the bird to the transect line.

The line transect method relies on several key assumptions, see Buckland et al. (1993, 2001, 2004, and 2015) for full explanation, and for greater detail on line transects in general:

1) *Birds on the transect line are detected with certainty.* Abundances may be underestimated if the assumption that g(x), which represents the probability of detection, is violated when g(0) = 1 (Buckland et al. 2001). The probability of detection decreases with distance from the transect line (Figure 1).

2) *Distances to birds are exact*. In order to generate accurate detection functions, perpendicular distances to the transect line must be accurate. This requires regular evaluation of radial distance estimations by observers using rangefinders and accurate measurement of angles for detected sightings, particularly for small angles (Thomas et al. 2010). Other line transect methods may require observers to estimate perpendicular distances directly, instead of radial distances and angles. Additionally, when encountering flocks of birds, distance from the centre of the flock to the transect line should be estimated (Buckland et al. 2001).

3) *Bird are detected at their original locations.* At sea, birds will exhibit vessel dependent behaviours. Evasive behaviours of seabirds, such as diving or fleeing are commonly observed (e.g., Lukacs et al. 2010). Such responses can reduce detectability close to the vessel and likely lead to underestimations of density (Buckland et al. 2015). In contrast, many species (e.g., albatrosses [*Phoebastria* spp.], gulls [*Larus* spp.], etc.) are attracted to vessels, due to potential scavenging opportunities (Montevecchi 2002). In those situations, more birds will be observed in proximity to the vessel than would naturally occur and thus density will likely be overestimated (Buckland et al. 2015). To reduce these biases, observers must remain vigilant, scanning ahead and recording sightings as soon as the bird is detected, as well as not double counting circling birds.

   As well, bird movement that is independent of the observer should be slow relative to the movement of the vessel. Flying birds may commonly move faster than the vessel and, as a consequence, a greater number of detections of flying birds will be encountered. This can lead to overestimations of density of flying birds (Buckland et al. 2015). ECCC Pacific Region continuously counts both flying birds and those on the water, analyzes these data separately, and acknowledges that continuous counts of flying birds does not represent ‘true’ flying bird densities (e.g., Fox et al. 2017). The Tasker snapshot method (Tasker 1984) is a common alternative or additional method used for surveying birds in flight. Integration of the Tasker (1984) approach for flying birds within a distance sampling method may pose complications when attempts are made to generate estimated densities for birds detected on the water and in flight, but see Fifield et al. (2017).

Perpendicular distances, calculated from the radial distance and angle recorded during surveys, or from observers’ estimates of perpendicular distances directly (Figure 1a), are plotted as a histogram and the resulting curve is fitted to the data. This is referred to as the detection function (Figure 1b; Buckland et al. 2001). The detection function should have a ‘shoulder’, meaning that the probability of detection stays close to 1 for some distance from the line, with detections then decreasing with distance from the observer (Figure 1b).

Marine birds may go undetected by observers for many reasons. Smaller species (Barbraud and Thiebot 2009), or those with darker plumage may be more difficult to detect on the water, particularly at higher sea states (Tasker et al. 1984, Evans Mack et al. 2002, Ronconi and Burger 2009). Distance from observers may also affect detectability, with the probability of detecting a bird generally being inversely related to its distance from the observer (Buckland et al. 2001). This premise is a central tenet of distance sampling, as the method uses the frequency of detections at different distances from the transect line to control for detectability and to calculate density estimates (Buckland et al. 2001).

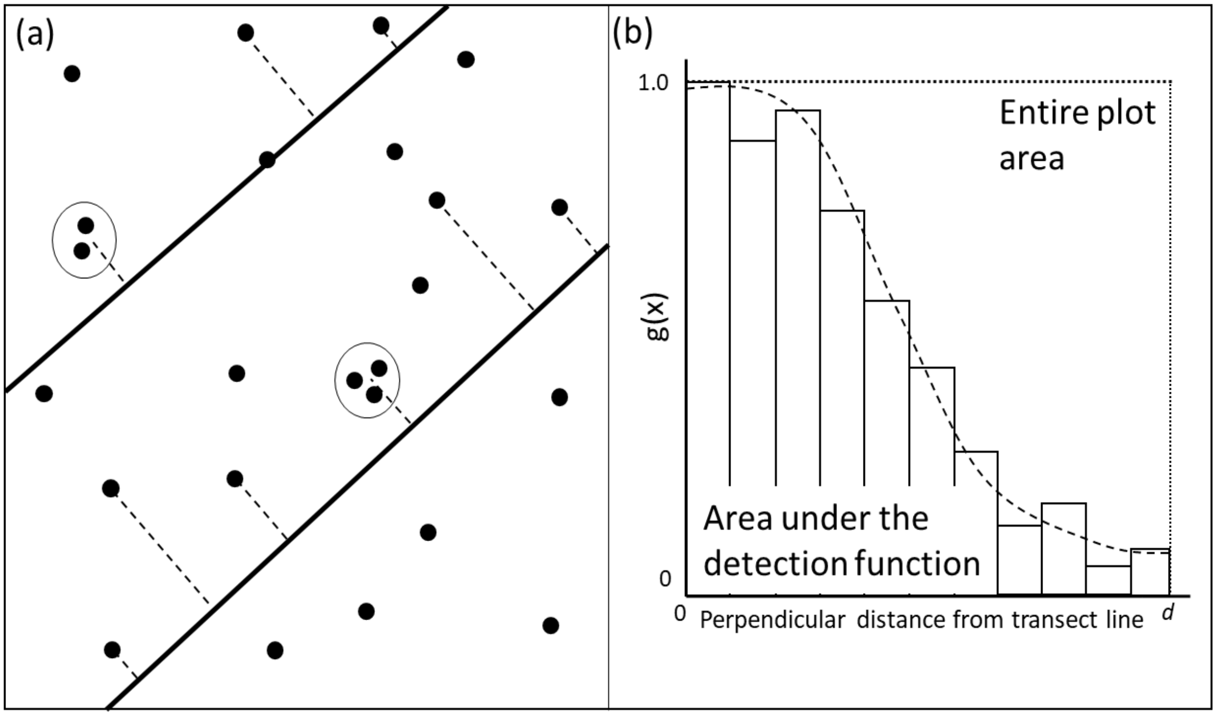

Figure 1. (a) Detected birds or clusters of birds (dots with dashed line) are recorded by a single port-side observer along two transect lines (solid lines). Dots without dashed lines represent birds that were not detected, or were on the starboard side of the vessel (i.e., out of transect). Perpendicular distance (dashed line) is calculated from radial distance and angle (or alternatively by estimating perpendicular distance directly). (b) the detection function (i.e., the probability of detecting a bird at perpendicular distance (*d*) from the transect line). The y-axis, g(x), represents the probability of detection. The resulting curve fitted to the data is the detection function (dashed line). Note the shoulder in the detection function as *d* approaches zero.

2.2 **Study design**

For surveys that employ line transect methods aboard ships-of-opportunity, study design opportunity is typically limited. Key considerations for surveys aboard ships-of-opportunity should include identification of survey objectives, and spatial and temporal coverage. With a ships-of-opportunity design, quantitative estimates of bird species abundance in a study area may not be possible. However, density estimates along transect segments, predictive modelling, and potentially qualitative trend analysis over time, may be achieved.

For surveys that employ line transect methods for marine birds aboard dedicated vessels, a good study design is a key prerequisite for high quality, reliable results (Thomas et al. 2010). One key design assumption of line transect distance sampling is that animals are distributed independently of the lines (Buckland et al. 2015). This assumption links to study design, in that a systematic, random design of line transects should be placed in the study area. For more information on study design, see Buckland et al. (2004 and 2015), Thomas et al. (2010), and others.

It is recommended that study objectives are fully articulated prior to survey initiation, as they will likely influence study design. If possible, a pilot project should be completed; alternatively or in complement, simulations using a range of possible, realistic data should be completed (Buckland et al. 2015). The study design should be explicit with respect to species of focus; does the project collect data on all marine bird species, or is there an emphasis on species in certain habitats, or species of conservation concern? Vessel-based line transect surveys that adopt a random, systematic transect design may not be the most appropriate approach for species in some habitats, such as waterfowl in nearshore habitats where individuals tend to aggregate along shorelines. A 'one-size-fits-all' survey design is unlikely to adequately capture the densities and distributions of all species. However, as much of the BC coast lacks marine bird baseline information and/or is without recent information, vessel-based line transect surveys offer opportunities to generate a quantitative baseline, and provide a fundamental resource for additional, more focused questions and hypotheses that may require more tailored surveys.

2.3 **Requirements for observing**

Line transect surveys often require observers to spend extended periods at sea. Observers must be prepared to work alone (if a single observer, one-sided survey is adopted) or more commonly in groups, on vessels of various sizes. Typically, observers are required to spend hours each day, maintaining a vigilant watch, and often during inclement weather. Depending on the season, vessel size and body of water surveyed, conditions on board can vary drastically. Observers should have experience working in rough seas and be aware of their susceptibility to seasickness.

Accurate data recording, attention to detail, and full adherence to the protocol are essential to ensure surveys are conducted efficiently and accurately. To ensure data accuracy, observers should have strong North Pacific Ocean marine bird identification skills and the ability to rapidly identify birds to the species level wherever possible, in all plumages and weather conditions. An understanding of marine bird ecology and behaviour is helpful.

Observers are expected to follow the survey protocol precisely and spend time revising and training with more experienced observers before beginning surveys. This includes regular training for accurate distance estimation with rangefinders. For ECCC Pacific Region line transect surveys, observers must conduct 100 distance estimates to an average accuracy of 15% prior to data collection. If their estimates exceed 15%, observers must continue to train prior to any data collection. Detection functions should also be generated for individual observers on a regular basis to detect potential issues with protocol adherence, such as 'guarding' the transect line (i.e., spending more time searching near the transect line).

2.4 **Methods**

2.4.1 Prior to surveys

For line transect surveys, each trained observer should have: a copy of the line transect protocol, a pair of binoculars, and a GPS device tethered to a mobile electronic device with a suitable data entry application installed. ECCC Pacific Region currently uses SeaScribe (BOEM 2019). See Appendix 1 for a complete list of recommended equipment.

Before beginning surveys, observers should familiarise themselves with the survey vessel and find the optimum viewing platform. Platforms should be outside, in the best viewing position, and should provide an unimpeded 90° view on at least one side of the vessel (if a single observer survey) or both the port and starboard. If observers are surveying on both sides of the vessel (i.e., one on port and one on starboard), the platform should have sufficient space for both observers to operate simultaneously and safely. For line transect surveys, two observer surveys (i.e., surveying on both sides of the vessel) are recommended, wherever feasible (Buckland et al. 1993, 2015).

Observers should use their judgement to ensure that the probability of detecting birds from 0-90° is not compromised on a given platform. The height of the observation platform and observer eye height above the water must be measured. Typically, eye height is measured in calm waters and calculated as deck height above the waterline plus observer eye height. If multiple vessels are used for surveys, observations should ideally be undertaken from platforms of a similar height. Note that platforms of varying height may also be included as a covariate in a planned distance sampling analysis. For current ECCC Pacific Region line transect surveys in coastal waters, including inlets, platform heights of greater than 3 m are preferred. Open ocean surveys will generally involve larger vessels with platforms heights greater than 5 m.

If employing a single observer system, the observer should choose which side of vessel they will survey before beginning a transect. Typically, this decision depends on environmental conditions such as the direction that minimizes the amount of glare, wind direction, fog, etc. As environmental conditions and/or the direction of travel changes, single observers should switch to the side that affords the best visibility. The location and time the change of side occurs must be accurately recorded.

2.4.2 Effort

While surveying, observers may be: on effort and on transect (i.e., for systematic surveys); on effort and on passage; or off effort and not surveying. Off effort is reserved for observer breaks and conditions too poor for observations (e.g., low light, poor weather conditions, etc.). Observers should always be on effort for transects and where feasible, should stay on effort while on passage between transects as much as possible. As observer fatigue is a concern, breaks should be taken while off transect. If multiple observers are present, staggered breaks should be taken to maximise survey effort. Overall, preference is given to observing while on designed transects, but observations while on passage are also highly valuable and should be conducted as often as possible.

Ideally, surveys are completed in fair to excellent conditions (e.g., Beaufort 0 or 1). Surveys must not be conducted in conditions where the observer deems that of 100% detection of birds on the transect line (i.e., at 0°) is no longer possible. Typically, from a platform height of approximately

3 m ECCC ceases surveying when sea state conditions reach Beaufort 5 or higher (Appendix 2; Table 2), when wind speed reaches approximately 25 nautical miles per hour (hereafter knots), and/or when glare, precipitation, smoke or fog impedes detections on the transect line. Note that maximum conditions listed are approximate. For example, ECCC at-sea surveys aboard 3 m platform height vessels in open ocean conditions tend to cease at 15-20 knots, whereas surveys aboard the same vessel in inlet and more sheltered waters may tolerate higher winds due to reduced fetch and subsequent wave heights. Environmental thresholds for surveys are also partially dependent on vessel size and platform height. On larger vessels with higher viewing platforms, it may be possible to survey in sea states greater than Beaufort 5. As well, when surveying on smaller vessels such as zodiacs, the threshold for effective surveys is likely to be substantially less than Beaufort 5. Observers must ensure that the fundamental assumptions of distance sampling are not being violated and make reasonable, conservative decisions regarding when to cease surveying.

If the vessel stops for any reason, observers should immediately cease surveying and restart once the vessel begins moving again. In situations where the survey vessel has been stationary for an extended period and/or has been dumping refuse over the side, wait a minimum of 10 minutes after the survey vessel is underway prior to starting observations to allow birds that have congregated around the vessel to be left behind.

2.4.3 Survey protocol

This line transect protocol is modified from Raphael et al. (2007) and Fox et al. (2017) and is intended to generate data that are comparable to existing line transect survey information in the region and integration with existing ECCC strip transect data, where needed. The protocol also includes continuous counts of flying birds, in part due to the existing ECCC strip transect protocol which also relies on continuous counts of flying birds.

Before beginning a transect, observers should record survey specific information and ambient environmental conditions (Table 3). For designed surveys, each transect line will typically be uniquely numbered when generated. From the observation platform, observers search for birds on one side of the vessel from 0° (i.e., on the transect line) to 90° (perpendicular to observer), in an arc (Figure 2). In order for all birds on the transect line to be detected, observers must survey continuously. Observers should scan using the naked eye from 0° to 90° and back again, with more time given to areas ahead of the vessel (i.e., most time spent evenly scanning 0° to 30°, less from 30° to 60°, and less again from 60° to 90°). A complete scan (0° to 90° and back to 0°) should take approximately 8 – 10 seconds. Binoculars should only be used for frequent and rapid scans from 0°- 30° to detect birds attempting to avoid the vessel, and for species identification from 0° to 90°. No maximum detection distance is defined for observations, but observers should concentrate primarily on birds ahead of the vessel and generally those in an area out to 300 m from the vessel. Common exceptions are large birds such as albatrosses and large aggregations that can be detected well beyond 300 m.

For two-sided observer surveys, scans are conducted between 0° and 90° on both the port and starboard sides simultaneously, with one observer on port, and one observer on starboard. Observers must communicate with each other to ensure that birds located close to, or crossing the transect line, are not double counted.

For each sighting, observers should record species, number of individuals, radial distance, angle and behaviour when first detected (Table 3). All detections from 0° to 90° should be recorded, regardless of distance or bird species identification. Both radial distance and angle estimations should be as exact as possible, with no rounding of values. To aid accurate angle measurements, fixed electronic (i.e., digital protractors), manual angle finders (i.e., large, angle boards similar to a large protractor with a moveable pointer), or similar should be used whenever possible. If helpful, observers should also construct a distance gauge from a transparent plastic ruler to aid with distance estimation when a clear view of the horizon is possible (Appendix 3; Figure 4). Sightings may consist of single individuals or groups of individuals that must be estimated if in large flocks (Appendix 4; Figure 5). Groups are defined by birds being located within 2 m, and/or exhibiting similar behaviour (e.g., flying flocks). For groups, radial distance and angle estimations should be to the centre of the group.

All birds should only be counted once. For taxa that follow and/or circle the vessel (e.g., albatrosses, gulls) or that tend to flush and land ahead again (e.g. shearwaters [*Ardenna* spp.], murres [*Uria* spp.], etc.), only a single sighting should be made. For following birds, observers should periodically look behind the vessel to track following individuals. If active fishing vessels are encountered during surveys, the position should be recorded as fishing vessels can influence the distribution of marine birds over tens of kilometres.

Large aggregations of birds on or above the water often occur (e.g., around bait balls) and their behaviours need to be reported separately. For each species or species group (e.g., unidentified gulls), observers should rapidly estimate the total number and then estimate the proportion flying and sitting on the water; report birds flying and on water as separate sightings. If a large flock is encountered with a portion of the flock off transect (i.e., on the other side of the vessel), such as would be commonly encountered on a single-sided survey, sightings should be based on the birds in transect only. If the flock later moves into transect, observers should adjust their count and behaviour data for the initial sighting. If the flock later moves out of transect, no changes are made to the sighting. Note that alternative approaches are to not record the sighting if the centre of the group is either off or otherwise out of transect (e.g., Gjerdrum et al. 2012). It is our experience with one-sided surveys in BC that extremely large groups of birds (often 1000s of birds in multi-species aggregations) may extend through port and starboard; previously, observers had been repeatedly challenged with applying the recommendation to exclude sightings with the centre off transect consistently. In particular, challenges were noted with detections of large aggregations of birds, which are sometimes dispersed along tide lines and detected at large distances; due to these issues, the ECCC Pacific Region protocol is to record birds based on in transect detections only.

When surveying, the vessel should be travelling at 8-10 knots (preferably 10 knots); however during busy sighting periods, observers need to maintain the assumption that all birds on the transect line will be detected. Slowing the vessel to 6 knots is permitted for a limited time to ensure all birds on transect are detected during busy periods. Vessels should not be moving slower than 5 knots and all data collected at less than 5 knots should be considered for exclusion from subsequent analyses.

When encountering large numbers of birds, observers need to maintain the assumption that all birds on the transect line will be detected. Time spent identifying difficult species, such as gulls, during busy (i.e., high density) periods can interfere with this assumption. Observers need to maintain vigilance ahead of the vessel, continue to scan as best they can as per the protocol, recognize that difficult-to-identify species may need to be identified at the group or family level, and that effective detection distances may be reduced. Audio data recording (as opposed to dictating to a data recording crew member) is more efficient in terms of number of sightings recorded per minute, and adoption of audio recording and then secondly, slowing the vessel to 6 knots if needed, will ensure that data collection is maximized during busy periods.

When approaching a transect, and particularly when turning sharply onto a transect, the vessel will often cause birds in the vicinity to flush or dive. To avoid missing these birds that would otherwise have been recorded when on effort, observers should sight any flushing or diving birds located near the planned transect on approach to the line (see Appendix 5; Figure 6). These sightings are then recorded when observers start the transect. Occasionally, an area at the beginning of a transect will be non-navigable for the survey vessel, whether due to depth, debris, log boom, or other obstruction. As the vessel approaches the navigable portion of the transect line, observers should back-scan approximately 300 m, or as far as is practical, and sight any birds that would have been recorded along the transect line in the non-navigable area. These sightings are recorded when observers start the transect (see Appendix 5; Figure 6). This approach is intended to make the beginning of the transect equivalent to the ending, where observers will 'look ahead' at the transect end by approximately 300 m.

When ending a transect and recording data electronically, observers may have several observations to record while the vessel is turning off transect. These observations should be made as quickly as possible (i.e., using audio recording) to avoid having to undertake post-survey data corrections (i.e., to place those final observations on the transect).

Table 3. Environmental and survey related variables recorded by observers undertaking ECCC marine bird line transect surveys. Table convention follows a single observer survey (i.e., either port or starboard, one-sided survey), but a two-sided survey is recommended for line transect surveys. Note that the maximum environmental conditions for undertaking line transect surveys relates to mid-sized vessels with a platform height of 3 m and greater. Higher Beaufort, wind, swell, and sightability categories may be suitable for larger vessels.

Variable Name	**Descriptor**
Survey Identifier	ECCC uses a standard format YYYYMMDD_SurveyArea_Vessel_ObserverInitials
Transect Identifier	Typically a number
Vessel Platform	Vessel name
Side Observed	Port or Starboard
Observer Position	Inside or Outside
Observer Name	Observer name
Eye Height [a]	> 1.5 m
Sea State [b]	Beaufort 0 – 5 [c]
Wind Speed	0 – approx. 25 knots
Visibility	0 km - unlimited
Swell Height	0 m – 5 m [d]
Precipitation [e]	No or Yes
Glare [f]	No or Yes
Fog	No or Yes
Smoke	No or Yes
Sightability [g]	1 - 5
Species	4-letter Alpha Code
Number of individuals	> 0
Behaviour	Flying, on water[h], on land
Radial distance from observer	0 m – unlimited [i]
Radial angle (from transect line)	0° - 90°

[a] Observer eye height = platform height + observer eye height. [b] See Appendix 2 for description. [c] Maximum sea state where surveys may be conducted is < Beaufort 5. [d] There may be exceptional circumstances where surveys can be conducted in conditions that meet or even exceed environmental thresholds; however, a key assumption of line transect surveys (i.e., that g(0) = 1) will need to be conservatively judged met. [e] Includes all forms of precipitation (rain, hail, snow, etc.). [f] If glare occurs within the area of observation. [g] Metric to encompass multiple

environmental variables; see Table 4 for ECCC sightability definitions. [h] Includes birds sitting on floating objects. [i]Observers may detect birds beyond 300 m; however, focus should be on birds within approximately 300 m of the vessel.

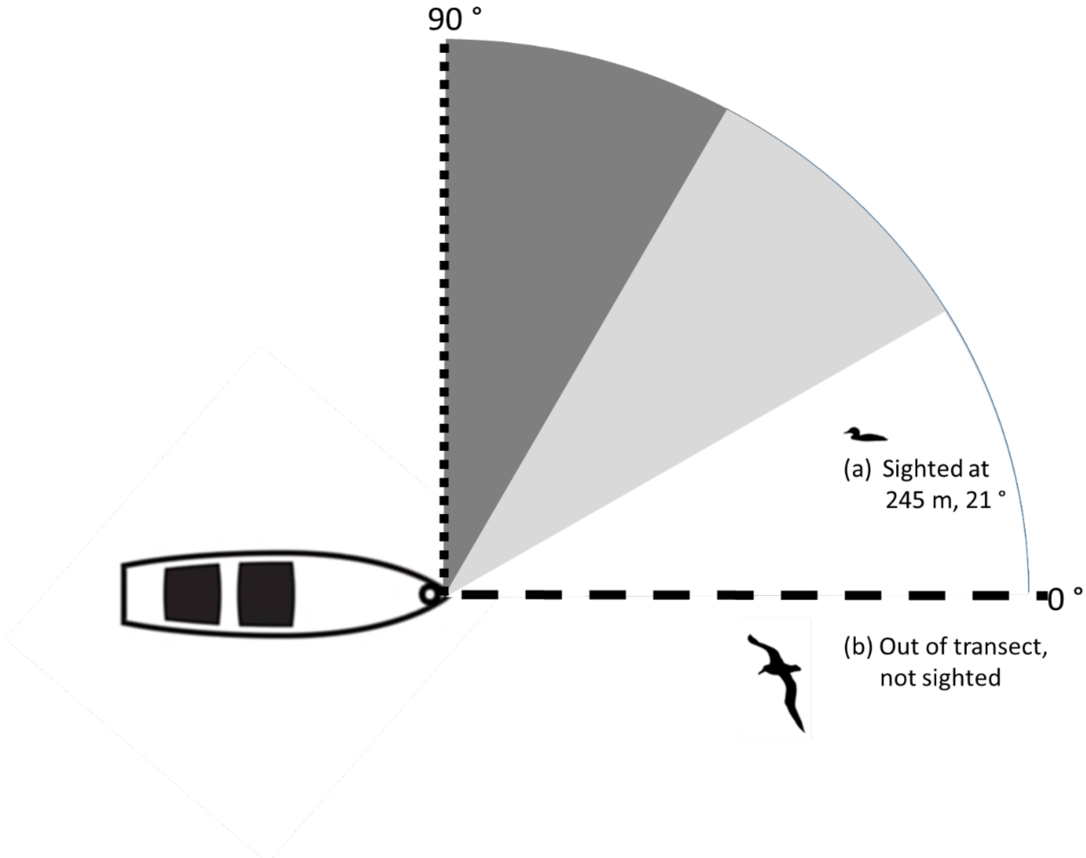

Figure 2. Graphical representation of a line transect survey with a single port side observer (circle) on a moving vessel travelling left to right. The transect line at 0° is represented by the dashed line, and 90 ° observation line is represented by the dotted line. Grey scale colours represent 30° segments within the observation area. Observer scans should take take 8 – 10 seconds with most time spent evenly scanning 0° to 30° (white), less from 30° – 60° (light grey), and less again from 60°- 90°(dark grey). The area within the dashed and dotted lines are considered in transect; however, there is no maximum distance for observations. Observers sight "in transect" birds as they are encountered. Bird (a), a loon (*Gavia spp.*), is sitting on the water at 245 m and 21°. Bird (b), an albatross (*Phoebastria spp.*), is "out of transect" and is therefore not counted unless it crosses the transect line at 0°. For single-sided surveys, the transect line at 0° should be aligned with the observer, and not the bow of the ship. For two-sided surveys, and depending on the protocol adopted, care should be taken to determine the transect line at 0° for each observer.

2.4.4 Environmental information

Accurate environmental data recording is important as weather conditions can strongly influence detectability. Environmental data must be updated every 30 minutes when surveying, or sooner if conditions change. Mandatory environmental data to be recorded for each transect are sea state (Appendix 2; Table 2), wind speed, swell height, and precipitation (Table 3). The presence of glare or fog and/or smoke within observer's 90° area of observation should also be recorded. ECCC also uses a generalized sightability metric (Table 4), which combines environmental variables such as sea state, wind, fog, and glare into one metric, which is useful for potential Multiple Covariate Distance Sampling (e.g., Marques et al. 2007, Fox et al. 2017).

Table 4. Sightability categories and definitions. Descriptions represent and/or conditions and are subject to observer generalization based on actual conditions. For example, with moderate light and otherwise good conditions, sightability is still considered to be a 3. Sightability categories relate to the approximate probability of counting a small, cryptic bird at distance (e.g., 200-300 m). These sightability categories have been developed for mid-sized vessels with a > 3 m observation platform and should be adapted based on the planned survey. Note that Beaufort may not directly apply in more sheltered or inlet locations. Modified from Fox et al. 2017.

Sightability	**Description**
1 - excellent	Beaufort 0-1. No fog or glare in viewing area. Clear weather, excellent lighting.
2 - good	Beaufort less than or equal to 2. Swell low (e.g., generally less <2 m). No white caps. No fog or glare in viewing area. Lighting good.
3 - moderate	Beaufort less than or equal to 3. Swell moderate (e.g., generally 1-4 m). If glare or fog, then does not impact detectability at 0-30°. Lighting moderate.
4 - poor	Beaufort less than or equal to 4. Swell high (e.g., generally 2-6 m). Visibility restricted due to wind, waves, fog, glare or other. 100% detection at 0° still deemed possible. Lighting poor.
5 - too poor to survey	Too poor to ensure 100% detection at 0° due to Beaufort greater or equal to 5. Swell extreme. Limited visibility due to wind, waves, fog, glare, light, or other.

2.4.5 Other taxa

Sightings of rare marine animals should be recorded when possible. For rare birds observed outside of the survey area, or while off transect, details needed are: species identification, number of individuals, behaviour (flying, on water, on land), latitude/longitude, and date. If possible, take photographs of the rarity.

Sightings of other rare species include: marine mammals (e.g., North Pacific right whale (*Eubalaena japonica*), common bottlenose dolphin (*Tursiops truncates*)); marine reptiles (e.g., leatherback sea turtle (*Dermochelys coriacea*), loggerhead sea turtle (*Caretta caretta*)); fishes (e.g., swordfish (*Xiphias gladius*)), and; sharks (e.g., basking shark (*Cetorhinus maximus*)) can be similarly recorded and should be reported to the Department of Fisheries and Oceans.

Observer discretion and the species involved should determine if the survey is halted in order to fully document and photograph the sighting. Vessel operators must maintain adherence to, and exceed wherever possible, Canada's marine mammal regulations (Marine Mammal Regulations, SOR/93-56).

2.4.6 Data recording

Due to the complexity of data recording and the vigilance needed to ensure all birds on the transect line are recorded, data may be recorded electronically by a data recorder. When there are many sightings, audio recordings made by the observer have been found to be more efficient, and allow observers to maximize the number of sightings recorded during busy periods. For ECCC surveys in the Pacific Region, the SeaScribe app (BOEM 2019) facilitates electronic data collection for at-sea surveys. The app also allows easy audio recordings, which means lone observers may also record audio sightings for later transcription. In order to collect accurate GPS data, the app SeaScribe should be tethered to an external GPS device. Users can create data collection forms specific to their protocol. Additional electronic data recording methods are also available, with more anticipated in future.

2.5 **Data Analyses**

Project objectives will ultimately determine the nature and scope of the data analyses. Several analytical engines are available for distance sampled data, including Conventional Distance Sampling, Multiple Covariate Distance Sampling, and Mark Recapture Distance Sampling, the latter being primarily used for double-platform line transect data. Density Surface Modelling (DSM; Hedley and Buckland 2004, Miller et al. 2013) is commonly an objective for line transect surveys of marine wildlife, with opportunities to undertake DSM within the standalone Distance software (Thomas et al. 2010) or associated R Statistical Software (R Core Team, 2021) package Distance (Miller et al. 2019). Alternatively, estimated densities along transect segments may be used in any DSM approach, such as ensemble Machine Learning (e.g., Fox et al. 2017). As with survey design, a wealth of guidance, examples, and training are available from authoritative sources (e.g., Buckland et al. 2004 and 2015, Hedley and Buckland 2004, Thomas et al. 2010, Miller et al. 2013, the Centre for Research into Ecological and Environmental Modelling at St. Andrews University, and others). Distance sampling courses and information may also be found here: https://workshops.distancesampling.org/online-course/index.html

3 STRIP TRANSECT PROTOCOL

3.1 **Introducing strip transects**

Strip transect surveying is a method of surveying populations to derive estimates of relative abundance and distribution. It is often used for at-sea vessel-based bird surveys due to the ease with which they can be organised and implemented (Hyrenbach et al. 2007). Strip transect surveys rely on the key assumption that all birds within the predefined strip width are recorded

(Hyrenbach et al. 2007). Typically, a maximum strip width of 250 m for surveys is applied by ECCC Pacific Region; however, 300 m strip widths are also common (e.g., Spear et al. 2004). As detectability of birds at sea can be strongly influenced by species, precipitation, sea state, and distance from the vessel (Ronconi and Burger 2009), strip width may be altered in an attempt to ensure that the key assumption is not violated (Hyrenbach et al. 2007). Observers must remain vigilant to ensure that all birds within the strip are counted so abundance is not underestimated.

ECCC Pacific Region employs continuous counts of flying birds when conducting strip transect surveys (e.g., Kenyon et al. 2009). Continuous counts, particularly when birds are travelling faster than the vessel, result in overinflated flying bird density estimates, or bird 'flux' (Spear et al. 1992). Tasker (1984) proposed using a series of instantaneous counts (often referred to as 'snapshots') as an alternative to continuous counts of flying birds to reduce or eliminate overinflation of density estimates due to bird flux. ECCC Pacific Region developed the continuous count component of the protocol prior to the development of the snapshot method (Tasker 1984); continuous counts of flying birds have been retained to ensure compatibility with historic data. Additionally, continuous counts of flying birds increase the likelihood of rare and uncommon species being recorded, and allows for comparison of estimated relative densities across space and time. However, note that the snapshot method (Tasker 1984) could be added to a continuous strip transect survey protocol, to allow for both continuous counts and snapshots of flying birds.

3.2 Study design

For surveys using strip transect methods aboard ships-of-opportunity, study design opportunities are typically limited. Similar to line transect surveys aboard ships-of-opportunity, key considerations for strip transect surveys aboard ships-of-opportunity should include survey objectives, funding constraints, availability of trained observers, and spatial and temporal coverage. Relative estimates of density along transect segments (e.g., Kenyon et al. 2009), predictive modelling, and potentially qualitative assessments of distributional or abundance trends, with important caveats and considerations, may still be achieved (see Miller et al. 2021). ECCC Pacific Region has conducted a limited number of short-term, strip transect surveys aboard dedicated vessels, given the sample sizes required for distance sampling (Buckland et al. 2015). In general, if a dedicated survey vessel is to be used and resources are available to ensure sufficient surveys, line transect surveys are recommended over strip transect, where feasible.

3.3 Requirements for observing

Strip transect surveys often require observers to spend extended periods at sea. Observers must be prepared to work alone (if a single, one-sided survey is adopted) or more commonly in groups, on vessels of various sizes. Typically, observers are required to spend hours each day, maintaining a vigilant watch, and often during inclement weather. Depending on the season, vessel size and body of water surveyed, conditions on board can vary drastically. Observers should have experience working in rough seas and be aware of their susceptibility to seasickness.

Accurate data recording, attention to detail, and full adherence to the protocol are essential to ensure surveys are conducted efficiently and accurately. To ensure data accuracy, observers should have strong North Pacific Ocean marine bird identification skills and the ability to rapidly identify birds to the species level wherever possible, in all plumages and weather conditions. An understanding of marine bird ecology and behaviour is helpful.

Observers are expected to follow the survey protocol precisely and spend time revising and training with more experienced observers before beginning surveys. If resources allow, a two-sided (i.e., port and starboard) survey with two observers allows for greater survey efficiency, data collection, and ultimately, more accurate estimations of relative density. ECCC Pacific Region's strip transect surveys generally rely on one observer, but two is preferred where feasible.

3.4 **Methods**

3.4.1 Prior to surveys

A recommended equipment list for conducting vessel-based surveys can be found in Appendix 1. For strip transect surveys, observer(s) must at a minimum have: a copy of the strip transect surveying protocol, a pair of binoculars, a distance gauge for estimating strip width (Appendix 3), a GPS device, and a synchronised time piece. Although not preferred, if entering data manually, observer(s) should have multiple copies of the strip transect survey data form (Appendix 6) and numerous pencils. If entering data electronically, observers should have a mobile device that can be tethered to an external GPS with a suitable data entry application installed. For electronic data collection, ECCC Pacific Region currently uses SeaScribe (BOEM 2019). If observers are conducting systematic line transects, the transect line coordinates should be provided to the vessel operator in advance of the survey.

On boarding the survey vessel, observer(s) should identify optimal viewing platforms. Platforms should be outside, and in the best viewing position. Ideally, the observer(s) should have an unimpeded 90° view of both the port and starboard sides of the vessel. If multiple observers are operating simultaneously, the platform should be large enough to accommodate both observers safely. For each platform, observer eye height above the waterline should be measured in calm water. Platform height and thus eye height is primarily determined by the size of the survey vessel. Observers should choose a platform on the vessel that optimises their ability to count birds for the ambient environmental conditions.

Before beginning surveys, observer(s) must determine the appropriate strip width, and for single observer surveys, a determination of which side of the vessel should be surveyed. Maximum strip width for transects in ideal conditions is 250 m using ECCC's method, although 300 m is also common. On lower platforms, where detecting birds at greater distances is difficult, strip width should be reduced to ensure all birds within the strip are detected. Strip width should also be reduced in poor weather conditions where visibility is affected (e.g., glare, wind direction, fog, etc.). Commonly strip width is reduced in 50 m increments, down to a minimum of 50 m. For single observer surveys, the decision to observe from port or starboard depends on prevailing environmental conditions, and the constraints imposed by the location of the viewing platform. Observation side and strip width must be recorded at the beginning of every survey, as well as during a survey if either changes.

3.4.2 Effort

When at sea in surveyable conditions, observer(s) should maximise survey effort. On ships-of-opportunity, observer(s) should aim to survey as much as is possible without fatigue influencing detections. For systematic transects, if a vessel is "on transect", observer(s) must be on effort. While the vessel is "on passage" (i.e., travelling off transect) observer(s) should survey whenever possible; however in cases of fatigue and if the vessel is unable to stop transiting, breaks may be taken while on passage. If multiple observers are present, breaks should be staggered to allow for continuous surveying. Overall, preference is given to observing while on transect, but observations while on passage are also highly valuable and should be maximized.

Observer(s) must stop surveying if the vessel dramatically alters course (e.g., 90° turn), slows down significantly (i.e., < 5 knots), goes off transect, or stops. Time and location must be noted, as well as the reason. If surveying aboard ships-of-opportunity, surveys can be restarted once the course change has been completed. In situations where the survey vessel has been stationary for an extended period and/or it has been dumping waste over the side, wait at least 5 - 10 minutes after vessel is underway to allow birds that have congregated around vessel to be left behind, or to have lost interest, prior to starting observations.

Aboard mid-sized vessels, ECCC halts surveys if sea state reaches Beaufort 5, or if wind speed exceeds 25 knots. However, surveys aboard larger vessels with a higher platform height may elect to have a higher threshold for survey conditions. Similarly, smaller, lower platform height vessels may require surveys to cease at lower Beaufort and wind speeds. Ultimately, those decisions should be made to ensure that the fundamental assumption of strip transect surveys, meaning that all birds are detected within the defined strip width, can be achieved. Although an upper limit of survey conditions is defined, observer(s) must use their best judgement and stop surveying when they can no longer ensure that all birds are being detected within the defined strip transect. This may occur below or above these identified limits in some conditions.

3.4.3 Survey protocol

When beginning a survey, observer(s) must record survey specific information and ambient environmental conditions (Table 5). Typically, if conducting systematic transects, each individual transect line (of varying lengths) will be uniquely numbered when generated. Typically, this transect line number should be used as the identifier. If conducting surveys from a vessel-of-opportunity, or on passage, observer(s) should use clear survey transect line identifiers that will prevent data loss due to inconsistent naming protocols. ECCC Pacific Region uses sequential numbers for strip transects that are part of an opportunistic survey. If entering data manually, observers should ensure that the GPS device is logging the vessel track before the transect begins and that observer timepieces are synchronised with the GPS device.

Table 5. Environmental and survey related variables recorded by observers undertaking one-sided strip transect surveys. Note that the maximum environmental conditions for undertaking strip transect surveys relates to mid-sized vessels with a platform height of 3 m and greater. Higher Beaufort, wind, swell, and sightability categories may be suitable for larger vessels.

Variable Name	**Descriptor**
Survey Identifier	ECCC uses standard format YYYYMMDD_SurveyStrata_Vessel_ObserverInitials
Transect Identifier	Typically a number
Vessel Platform	Vessel name
Side Observed	Port or Starboard
Strip Width	50 m – 300 m[a]
Observer Position	Inside or Outside
Observer Name	Observer name
Time [b]	Time transect begins
Eye Height [c]	> 1.5 m
Sea State[d]	Beaufort 0 – 5 [e]
Wind Speed	0 – approx. 25 knots [f]
Visibility	0 km – unlimited km
Swell Height	0 m – 8 m
Precipitation [g]	No or Yes
Glare [h]	No or Yes
Fog	No or Yes
Smoke	No or Yes
Sightability [i]	1-5
Species	4-letter Alpha Code
Number of Individuals	> 0
Behaviour	Flying, on water [j], on land

[a] 50 m increments. [b] If entering handwritten, manual data. [c] Observer eye height = platform height + observer eye height. [d] See Appendix 2 for descriptions. [e] Maximum sea state for surveys is generally < Beaufort 5. [f] Maximum wind speed for surveys to be conducted in is approximately 25 knots, [g] Includes all forms of precipitation (rain, snow, sleet, etc.). [h] If glare occurs within area

of observation. [i]Metric to encompass multiple environmental variables, used for line transect sampling; see Appendix 9 for ECCC sightability definitions. Sightability used for strip transect protocol only for integration with line transect protocol.[j]Includes birds sitting on floating objects.

When surveying, observer(s) scan in an arc beginning in front of the vessel at 0° and ending at 90° abeam (Figure 3). Observers may use binoculars to scan. The survey area is limited to the predetermined strip width (usually 250 m), unless conditions or a lower eye-height vessel necessitate a reduced strip. Scans are continuous throughout the survey period.

If multiple observers are present, scans are conducted between 0° and 90° on both the port and starboard sides simultaneously. While some overlap in the area scanned near 0° is unavoidable, paired observers must ensure that birds located close to, or crossing in front of the vessel are not double counted. Observations close to 0° should be communicated between observers to ensure double counts do not occur.

When observer(s) detect any bird within the strip they must record: species identification, number of individuals, and behaviour when first detected (Table 5). Observer(s) must ensure all detections are recorded regardless of identification success. Birds unidentified to the species level should be recorded at the family or genus level if possible (e.g., unidentified gull, unidentified goldeneye), although unidentified birds can simply be recorded as unidentified, if necessary.

Sightings may consist of single individuals or groups of individuals (See Appendix 4; Figure 5). Groups are defined by birds being located within 2 m, or otherwise exhibiting similar behaviour (e.g., flying flocks). For groups to be recorded, the centre point of the group must be within the strip.

Some marine bird species exhibit attraction to vessel, by being attracted to, following, and/or repeatedly circling vessels. There is a risk of counting these birds multiple times; consequently, the observer(s) should occasionally look behind the vessel to determine if birds are following and attempt to track circling individuals. Albatrosses can be particularly difficult, but shearwaters, northern fulmars (*Fulmarus glacialis*), and gulls commonly exhibit attractive responses.

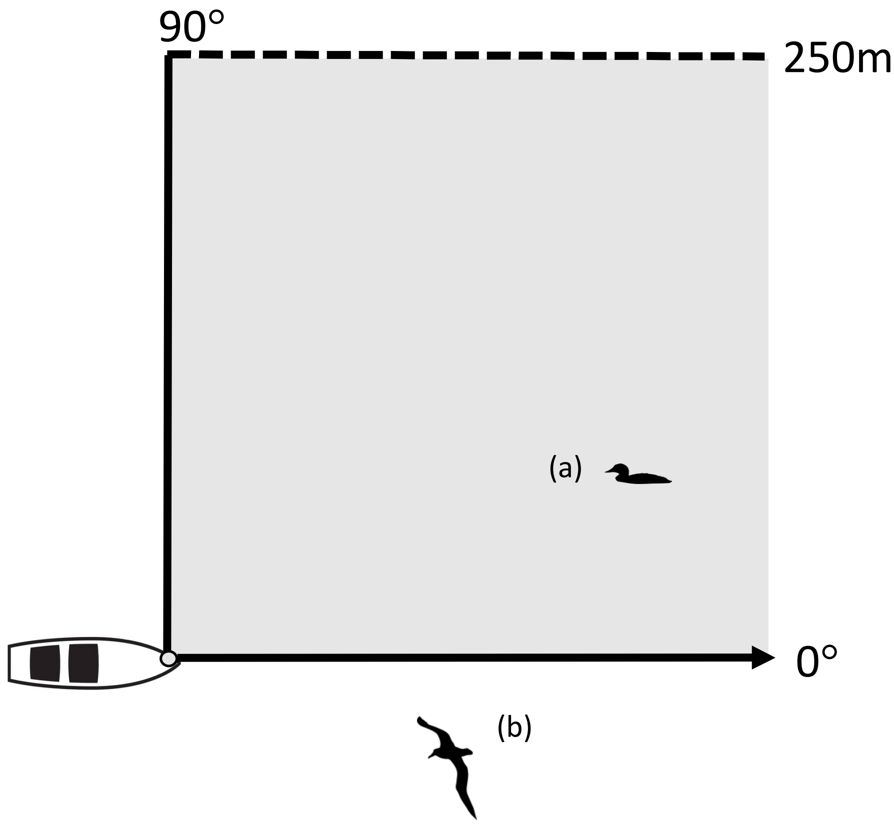

Figure 3. Graphical representation of strip transect surveys on a moving platform. The “in transect” area is shaded grey. An observer (grey dot) situated on the port side of a moving platform is conducting strip transect surveys with a maximum strip width of 250m. Bird (a), a loon, is in transect and counted. Bird (b), an albatross, is out of transect and would not be counted unless it crosses into the in transect area. For single-sided surveys, the transect line at 0° should be aligned with the observer, and not the bow of the ship. For two-sided surveys, and depending on the protocol adopted, care should be taken to determine the transect line at 0° for each observer.

3.4.4 Environmental information

Accurate environmental data recording is important as weather conditions strongly influence detectability. Environmental data must be updated every 30 minutes when entering data electronically, or sooner if conditions change. When entering data manually, conditions must be recorded at the beginning of each survey period, or if a change occurs. Mandatory environmental data to be recorded are listed in Table 5.

3.4.5 Other taxa

Sightings of rare marine animals should be recorded when possible. For rare birds observed outside of the survey area, or while off transect, details needed are: species identification, number of individuals, behaviour (flying, on water, on land), latitude/longitude, and date. If possible, take photographs of the rarity.

Sightings of other rare species include: marine mammals (e.g., North Pacific right whale (*Eubalaena japonica*), common bottlenose dolphin (*Tursiops truncates*)); marine reptiles (e.g., leatherback sea turtle (*Dermochelys coriacea*), loggerhead sea turtle (*Caretta caretta*)); fishes (e.g., swordfish (*Xiphias gladius*)), and; sharks (e.g., basking shark (*Cetorhinus maximus*)) can be similarly recorded and should be reported to the Department of Fisheries and Oceans.

Observer discretion and the species involved should determine if the survey is halted in order to fully document and photograph the sighting. Vessel operators must maintain adherence to, and exceed wherever possible, Canada's marine mammal regulations (Marine Mammal Regulations, SOR/93-56).

3.4.6 Data recording

Historically, ECCC has recorded strip transect survey data manually; however in recent years, the development of mobile device applications for at-sea surveying has facilitated efficient electronic data collection.

Manual data collection recording sheets can be found in Appendix 6. If collecting data manually, observer(s) must ensure that their timepiece is synchronised with the GPS used to log vessel tracks so that sightings can be accurately mapped. As well, a person to record the data is recommended, wherever feasible, for manual data collection.

SeaScribe is an app that ECCC Pacific Region uses for electronic data collection during at-sea surveys (BOEM 2019). In order to accurately collect data with SeaScribe, the mobile device should be tethered to an external GPS device.

3.5 **Data Analyses**

The generation of density estimates (i.e., the number of birds per unit area) for strip transect sampled data is typically straightforward. Until recently, ECCC Pacific Region surveys relied on five minute transect 'segments'; the length of the segment and the width of the strip was used to calculate area and subsequently determine the density of bird species or groups per km^2. With a recent shift to electronic data collection, transect segment lengths can be determined at a specified length during the data processing phase. The same principles of calculating surveyed area based on transect segment length and strip width are simply applied to generate marine bird density estimates during processing. In many survey program scenarios, estimates of marine bird species or group densities along transect segments represent a primary data product. However, these data may also be used in use modelling (e.g., Fox et al. 2017), or for qualitative assessments of marine bird distributional and abundance trends.

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Appendix 1. **EQUIPMENT LIST FOR CONDUCTING MARINE BIRD SURVEYS**

DS = distance sampling line transect surveys, SS = strip transect surveys

Binoculars (including backup pair), lens cleaner and cloths (SS/DS)
Electronic range finder (DS)
Clear ruler and black permanent marker for distance gauge construction (SS/DS)
Rubbing alcohol for erasing permanent marker (SS/DS)
Angle finder (manual only for wet platforms; manual and electronic for dry platforms (DS)
Camera and lens (SS/DS)
Binder with transect information (transect maps and GPS coordinates in the appropriate format for vessel's navigation system (SS/DS)
Manual data entry sheets (SS/DS)
Waterproof tablet device and backup device with data entry application installed (SS/DS
GPS device (capable of tethering to tablet for electronic data entry), backup GPS device (SS/DS)
Communication safety devices (e.g., Satellite phone, inReach, Spot device) (SS/DS)
Marine first aid kit for vessels (SS/DS)
Floatation coat and pants (one per observer) (SS/DS)
Lifejacket (one per observer) (SS/DS)
Marine charts (SS/DS)
Batteries if required, battery packs/ chargers and sufficient charging cables, multiple outlet power bar (SS/DS)
Bird ID reference materials; observer's choice (SS/DS)
Warm and waterproof clothing (SS/DS)
Hat, sunglasses and sunscreen (SS/DS)

Appendix 2. BEAUFORT SCALE, TRUE WIND SPEED, AND SEA STATE

Table 2. Beaufort scale, true wind speed, and sea state (Environment Canada, 2017). An illustrated Beaufort Scale is also available in the SeaScribe app. This metric was developed for open waters and thus will not always be directly applicable to conditions in more sheltered waters.

Beaufort Scale	Wind Speed		Sea Conditions
	km/hr	knots	
0	<1	<1	Calm. Sea surface like a mirror, but not necessarily flat
1	1-5	1-3	Light air. Ripples with the appearance of scales are formed, but without foam crests
2	6-11	4-6	Light breeze. Small wavelets, still short but more pronounced. Crests do not break. When visibility good, horizon line always very clear.
3	12-19	7-10	Gentle Breeze. Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered whitecaps.
4	20-28	11-16	Moderate breeze. Small waves, becoming longer. Fairly frequent whitecaps.
5	29-38	17-21	Fresh breeze. Moderate waves, taking a more pronounced long form. Many whitecaps are formed. Chance of some spray.
6	39-49	22-27	Strong breeze. Large waves begin to form. The white foam crests are more extensive everywhere. Probably some spray.
7	50-61	28-33	Near gale. Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.
8	62-74	34-40	Gale. Moderately high waves of greater length. Edges of crests begin to break into the spindrift. The foam is blown in well marked streaks along the direction of the wind.
9	75-88	41-47	Strong gale. High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over.
10	89-102	48-55	Storm. Very high waves with long overhanging crests. Dense white streaks of foam. Surface of the sea takes a white appearance.
11	103-117	56-63	Violent storm. Exceptionally high waves. Sea completely covered with long white patches of foam.
12	118-133	64-71	Hurricane. Air filled with foam and spray. Sea entirely white with foam. Visibility seriously impaired.

Appendix 3. **MANUAL CALCULATIONS FOR DISTANCE ESTIMATION**

To aid visual distance estimation at sea, a rangefinder can be constructed from a transparent plastic ruler using a formula derived from Heinemann (1981). SeaScribe provides an electronic version of this calculation.

$$d_h = 1000\frac{(ah3838\sqrt{h}) - ahd}{h^2 + 3838d\sqrt{h}}$$

e.g., if $a = 0.91$, $h = 6.82$m and $d = 200$

then $d_h = 30$mm

Where:

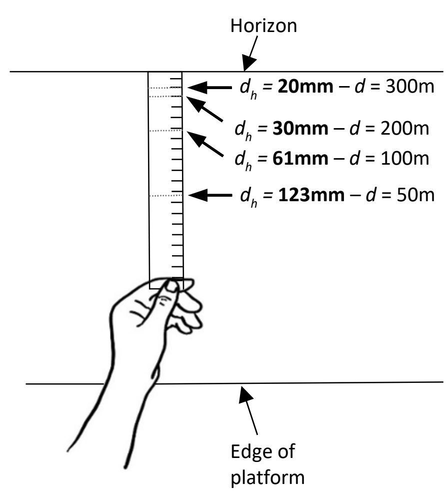
d_h = distance below horizon on the ruler (mm).

a = distance between observer's eye and ruler when observer's arm fully out stretched (m)

h = hight of observer's eye above waterline at observation point (m; deck height plus observer eye height)

d = distance to be estimated (m; separate calculation for each distance)

With 0 mm denoting the horizon, mark distances (d) along the ruler at the calculated d_h values (Figure 4). To use the rangefinder hold the ruler, arm outstretched, with 0mm aligned with the horizon. Looking through the ruler, the marks denote distance from the observer. Calculations



must be updated to reflect differences in observer measurements or platform height.

Figure 4. Distance estimation using a distance gauge constructed from a transparent plastic ruler with $a = 0.91$m, $h = 6.82$m (adapted from Gjerdrum et al. 2012).

Appendix 4. **METHOD FOR COUNTING LARGE NUMBERS OF FLOCKING BIRDS**

Most observers tend to underestimate large flocks. Underestimating can be reduced with regular training and testing. Photographs can be used to train when not in the field. Regardless of whether you are using photographs or actual flocks (in the field) you should become familiar with the following process for estimating flock sizes.

Starting at one end of flock, visually break it into blocks of 10, 50, or 100. Use smaller units if the flock is more dispersed. Using a mental image of what your chosen block size looks like, estimate the number of blocks needed to encompass the entire flock. Multiply the number of blocks by the number of birds per block to derive an estimate of flock size. Note that flocks of birds in flight extend in three dimensions (i.e., distant flocks appear more densely packed, with many birds hidden behind other members of the flock.

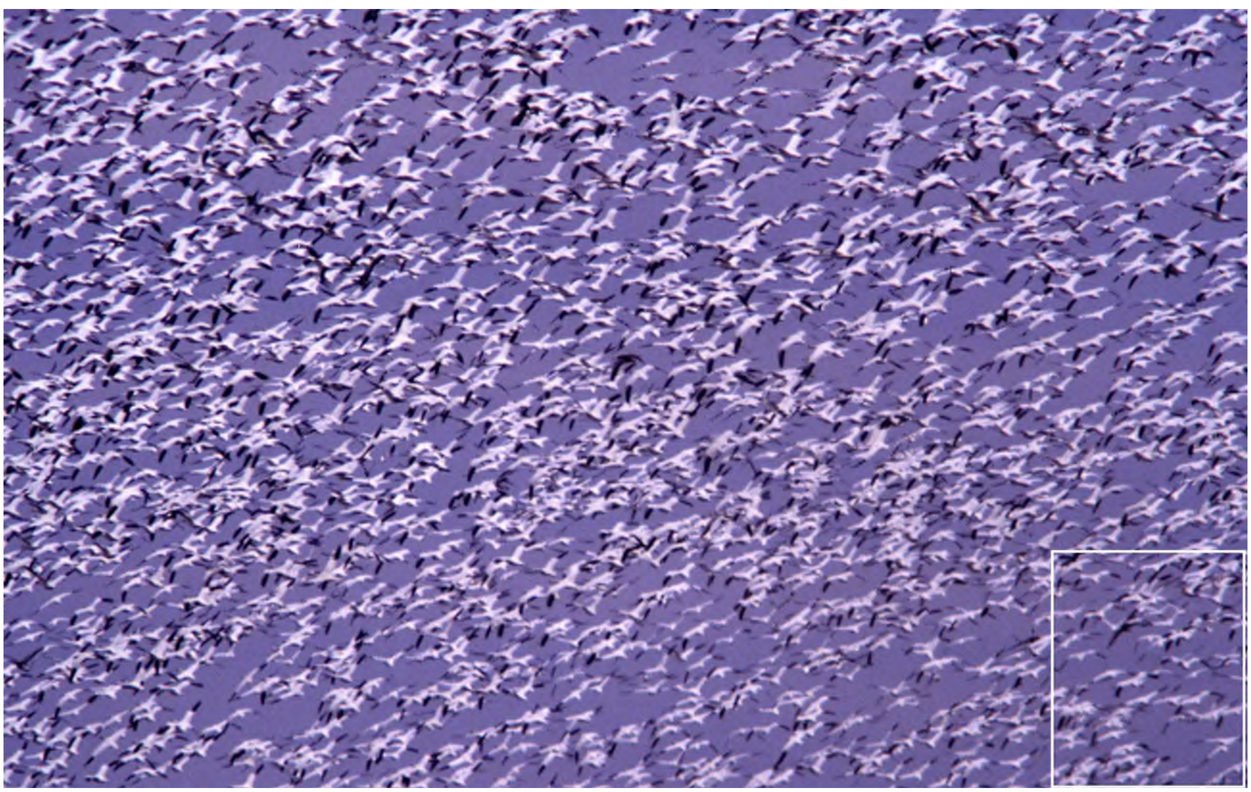


Figure 5. Flock of Snow Geese (*Anser caerulescens*) in flight. White box contains approximately 50 geese. Photo Credit: USFWS

Appendix 5. **DETECTING BIRDS WHEN STARTING A LINE TRANSECT**

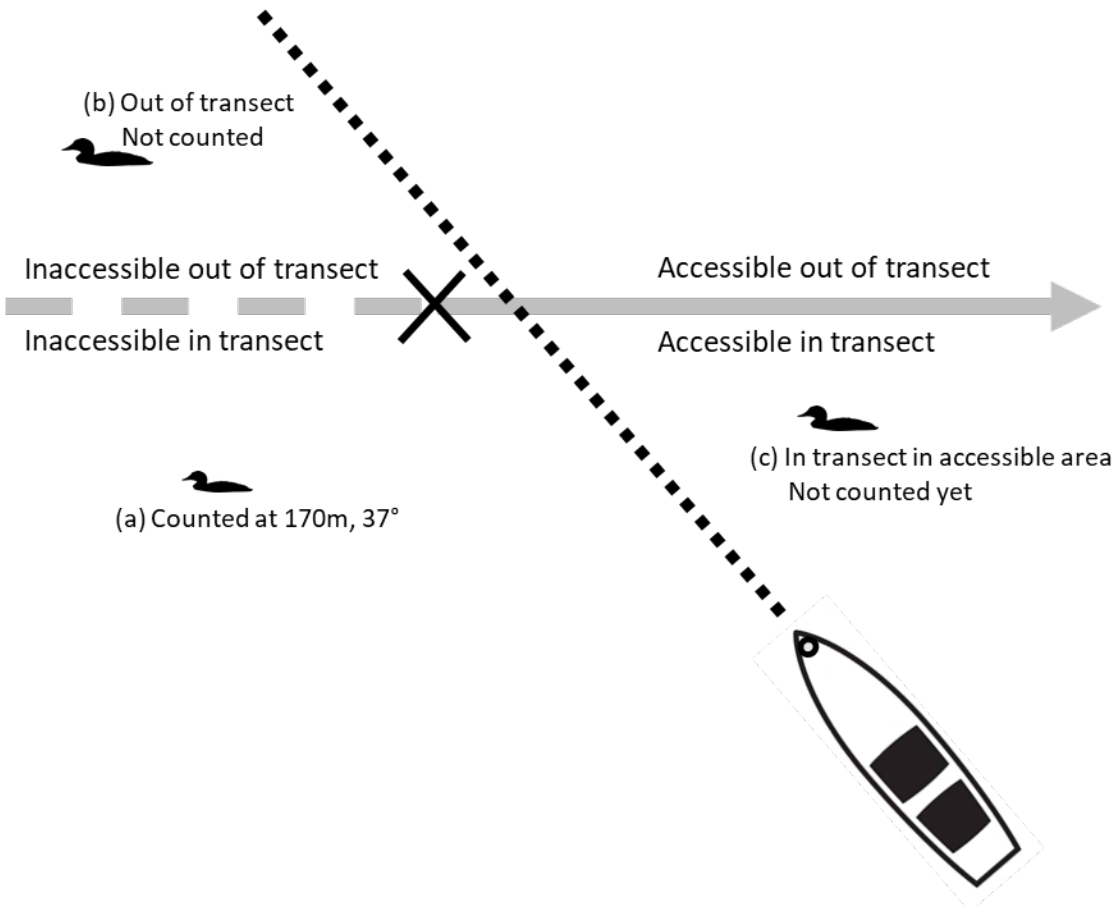


Figure 6. Starboard observer, using a one-sided line transect method, approaches a transect (grey line). Dashed grey line represents a non-navigable portion of the planned transect. Black dotted line indicates the approaching path (and 0°) for a single observer. Notations a, b, c represent birds close to the transect line.

Detecting Birds When Starting a Line transect

The beginning of the transect line (dashed grey line) is inaccessible (e.g., non-navigable), but visible. Any "in transect" birds in this inaccessible area should be counted. Survey effort on transect will begin where the transect becomes accessible (black X).

As the observer positioned on the starboard side of the vessel approaches the transect, they should attempt to count any "in transect" birds that flush or dive. They will also count all "in transect" birds that do not flush or dive that are in the inaccessible area (focusing on an area within approximately 300m of the beginning of the transect, as per the protocol). "In transect" birds in the accessible area that do not flush, or dive are not recorded at this point, as these will be encountered once the transect begins.

Sightings made while approaching the transect line are not recorded until the observer reaches point X, where observations are then recorded.

- Bird A, regardless of behaviour is counted, as it is considered "on transect", despite being on the port side of the vessel during the approach.
- Bird B is located "out of transect". This bird is not counted, unless it flushes and crosses into the "in transect" area.
- Bird C is located "in transect" in the accessible area. It is not counted until the observer begins the transect. If the bird flushes or dives before the observer reaches the line, then the bird is counted.

This issue of attempting to observe and report flushing and diving birds is common when starting transects against a shoreline. While other approaches may be to exclude all birds until the vessel is 'on transect', our experience is that this would result in the loss in a potentially significant number of birds, particularly those associated with shorelines.

Appendix 6. **EXAMPLE STRIP TRANSECT SURVEY DATA MANUAL DATA ENTRY FORM**

Date	Transect ID	Observer	Page No.
Survey Platform	Position: Port / Starboard	Observer Eye Height	Observing Location: Inside / Outside
Sea state (Beaufort)	Visibility (km)		Strip Width (m)
True Wind Speed (knots)	Swell Height (m)		Sightability
Fog: Y / N	Glare: Y / N	Precipitation: Y / N	Smoke: Y / N

Ensure the GPS device is synchronised with the timing device for accurate sighting locations.

Start Time:

Observation Timestamp	**Alpha Code**	**Count**	**Behaviour**	**Observation Comments**

Notes:

End Time:

*Behaviour relates to flying, on water, or land. Transect identification number (Transect ID), Page Number (Page No.), and Sightability are optional, depending on the survey.