Survey Methods, Data Collections, and Species Observations from the 2015 Survey to SGaan Kinghlas-Bowie Marine Protected Area

K.S.P. Gale, J.M.R. Curtis, K.H. Morgan, C. Stanley, W. Szaniszlo, L.A. Burke, L.N.K. Davidson, B. Doherty, G. Gatien, M. Gauthier, S. Gauthier, D.R. Haggarty, D. Ianson, A. Neill, J. Pegg, K. Wallace, and J.D.M. Zand

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2017

SURVEY METHODS, DATA COLLECTIONS, AND SPECIES OBSERVATIONS FROM THE 2015 SURVEY TO S<u>G</u>AAN <u>K</u>INGHLAS-BOWIE MARINE PROTECTED AREA

By

K.S.P. Gale[1], J.M.R. Curtis[2], K.H. Morgan[3], C. Stanley[1], W. Szaniszlo[4], L.A. Burke[5], L.N.K. Davidson[6], B. Doherty[7], G. Gatien[1], M. Gauthier[1], S. Gauthier[1], D.R. Haggarty[2], D. Ianson[1], A. Neill[8], J. Pegg[2], K. Wallace[9], and J.D.M. Zand[9]

[1]Fisheries and Oceans Canada, Science Branch, Pacific Region, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, BC, Canada V8L 4B2

[2]Fisheries and Oceans Canada, Science Branch, Pacific Region, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, BC, Canada V9T 6N7

[3]Canadian Wildlife Service, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, BC, Canada V8L 4B2

[4]Independent contractor, Ucluelet, BC, Canada

[5]School of Environmental Studies, University of Victoria, 3800 Finnerty Road, Victoria, BC, Canada V8P 5C2

[6]Earth to Ocean Research Group, Simon Fraser University, Burnaby, BC, Canada V5A 1S6

[7]Quantitative Fisheries Research Group, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC, Canada V5A 1S6

[8]Department of Biology and School of Earth and Ocean Sciences, University of Victoria, 3800 Finnerty Road, Victoria, BC, Canada V8P 5C2

[9]Highland Technologies, Inc., 525 Caleb Pike Road, Victoria, BC, Canada V9B 6G8

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Abstract

Gale, K.S.P., Curtis, J.M.R., Morgan, K.H., Stanley, C., Szaniszlo, W., Burke, L.A., Davidson, L.N.K., Doherty, B., Gatien, G., Gauthier, M., Gauthier, S., Haggarty, D.R., Ianson, D., Neill, A., Pegg, J., Wallace, K., and Zand, J.D.M. 2017. Survey Methods, Data Collections, and Species Observations from the 2015 Survey to SGaan Kinghlas-Bowie Marine Protected Area. Can. Tech. Rep. Fish. Aquat. Sci. 3206: vii + 94 p.

Bowie Seamount, which has a minimum depth of 24 m and is located approximately 175 km west of Haida Gwaii, is the shallowest seamount in Canada's Pacific Exclusive Economic Zone (EEZ). Initial research on the biology of Bowie Seamount, coupled with interest from the Haida Nation, led to Bowie Seamount and the adjacent Hodgkins and Davidson (also called Pierce or Peirce) Seamounts being designated in 2008 as the SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA), which is co-managed by the Government of Canada and the Council of the Haida Nation.

In July 2015, Fisheries and Oceans Canada (DFO) led a research survey (PAC 2015-48) to study the biology and oceanography of SK-B MPA. The research objectives of the survey were to 1) characterize the biodiversity, benthic community structure, and habitat in management Zones 2 and 3 of SK-B MPA; 2) contrast the planktonic community and chemical oceanography within and outside the boundaries of SK-B MPA in order to quantify the ecological and biological significance of seamounts within the MPA; and 3) collect opportunistic data on the seabird and marine mammal species occurrences within and outside the MPA boundaries and while in transit to and from the MPA. PAC 2015-48 was the pilot survey for "BOOTS", DFO's newly developed deep-sea towed camera system, which was used to collect benthic imagery (still photos and video) and had an attached CTD to record water properties.

This report provides background information on the geology, biology, and historical fisheries at SK-B MPA, and describes the 2015-48 survey design, methodologies, data processing, and basic analyses of the benthic video, hydro-acoustic, plankton, CTD, seabird, and marine mammal surveys. Documentation on the instrumentation and operating procedures for the BOOTS tow-camera are also provided.

Overall, 124 benthic taxa (including morphotypes) were observed from 17 tow-camera dives carried out between 249 m and 1246 m depth on Bowie and Hodgkins Seamounts. This report complements a photo-documented inventory of species observed at SK-B MPA during benthic imagery surveys carried out in 2000, 2011, and 2015 (Gauthier et al. 2018a, b, c). No fishing gear was observed in SK-B MPA, but there was some evidence of drag marks on the seafloor and potential damage to corals. There were 11 species of seabird observed within 50 km of Bowie Seamount, with the majority of observations being Fork-tailed and Leach's Storm-Petrels (*Hydrobates furcatus and H. leucorhous*). Seven species of marine mammals were observed over the course of the survey, with Dall's Porpoise (*Phocoenoides dalli*), Fin Whale (*Balaenoptera physalus*), and a large group of Northern Right Whale Dolphins (*Lissodelphis borealis*) encountered in the Bowie Seamount area. Acoustic data, zooplankton samples, CTD casts, and water samples were collected along a survey grid and will be analyzed to assess the distribution of biota in and around the area of Bowie Seamount.

This report will act as metadata for the information collected during the 2015 survey, and a basis for future analyses on the biology and oceanography of Bowie Seamount and SK-B MPA.

Résumé

Gale, K.S.P., Curtis, J.M.R., Morgan, K.H., Stanley, C., Szaniszlo, W., Burke, L.A., Davidson, L.N.K., Doherty, B., Gatien, G., Gauthier, M., Gauthier, S., Haggarty, D.R., Ianson, D., Neill, A., Pegg, J., Wallace, K., and Zand, J.D.M. 2017. Méthodes de relevé, collecte des données et observations des espèces – Relevé de 2015 dans la zone de protection marine SGaan Kinghlas. Rapp. tech. can. sci. halieut. aquat. 3206: vii + 94 p.

Le mont sous-marin Bowie, dont la profondeur minimale est de 24 m et qui se situe à environ 175 km à l'ouest de Haida Gwaii, est le mont sous-marin le moins profond de la zone économique exclusive du Pacifique au Canada. Les recherches initiales sur la biologie du mont sous-marin Bowie, en plus de l'intérêt démontré par la Nation haïda, ont mené à la désignation, en 2008, du mont sous-marin Bowie et des monts sous-marins adjacents Hodgkins et Davidson (aussi appelé Pierce ou Peirce) comme la zone de protection marine SGaam Kinghlas-Bowie (ZPM SK-B), une zone maintenant gérée conjointement par le gouvernement du Canada et le Conseil de la Nation haïda.

En juillet 2015, Pêches et Océans Canada (MPO) a dirigé un relevé de recherche (PAC 2015-48) dans le but d'étudier la biologie et l'océanographie de la ZPM SK-B. Les objectifs du relevé de recherche étaient les suivants : 1) caractériser la biodiversité, la structure des communautés benthiques et les habitats des zones de gestion 2 et 3 de la ZPM SK-B; 2) comparer la communauté planctonique et l'océanographie chimique à l'intérieur et à l'extérieur des limites de la ZPM SK-B afin de quantifier l'importance écologique et biologique des monts sous-marins dans la ZPM; 3) recueillir des données fortuites sur les occurrences d'espèces d'oiseau de mer et de mammifère marin se trouvant à l'intérieur et à l'extérieur des limites de la ZPM et se dirigeant vers, ou quittant cette dernière. Le relevé PAC 2015-48 a servi de relevé pilote pour le système « BOOTS », le tout nouveau système de caméra remorquée conçu pour l'observation en profondeur. Il a permis de recueillir des images benthiques (photos fixes et vidéos) et d'enregistrer des propriétés hydriques grâce à un dispositif de conductivité, température et profondeur (CTP).

Le présent rapport fournit des renseignements contextuels sur la géologie, la biologie et les pêches historiques de la ZPM SK-B, en plus d'expliquer la conception, les méthodologies et le processus de traitement des données du relevé 2015-48 et de fournir une analyse de base de la vidéo benthique et des relevés liés aux données hydroacoustiques, au plancton, aux mesures CTP, aux oiseaux de mer et aux mammifères marins. Il fournit également des renseignements sur l'instrumentation et les procédures d'exploitation du système de caméra remorquée BOOTS.

Dans l'ensemble, 124 taxons benthiques (y compris des morphotypes) ont été observés par la caméra remorquée dans le cadre de 17 plongées effectuées à une profondeur variant entre 249 et 1 246 m dans la région des monts sous-marins Bowie et Hodgkins. Le présent rapport vient compléter un répertoire photo des espèces observées dans la ZPM SK-B durant les relevés d'imagerie benthique menés en 2000, en 2011 et en 2015 (Gauthier et al., 2018a, b, c). Bien qu'aucun engin de pêche n'ait été observé dans la ZPM SK-B, des marques de dragage sur le fond marin ainsi que des dommages possibles aux coraux ont été remarqués. Onze espèces d'oiseaux de mer ont été recensées à 50 km à la ronde du mont sous-marin Bowie, et la majorité d'entre eux étaient des pétrels à queue fourchue et des océanites cul-blanc (*Hydrobates furcatus* et *H. leucorhous*). Sept espèces de mammifère marin ont été observées durant le relevé, dont des marsouins de Dall (*Phocoenoides dalli*), des rorquals communs (*Balaenoptera physalus*) et un grand groupe de dauphins à dos lisse (*Lissodelphis borealis*) dans la région du mont sous-marin Bowie. Des données acoustiques, des échantillons de zooplancton, des coups de sonde CTP et des échantillons d'eau ont été prélevés en fonction d'un quadrillage de relevé, et ceux-ci seront analysés afin d'évaluer la répartition du biote à l'intérieur et autour de la région du mont sous-marin Bowie.

Le présent rapport servira de métadonnées pour l'information recueillie durant le relevé de 2015 et de données de base pour les analyses futures de la biologie et de l'océanographie du mont sous-marin Bowie et de la ZPM SK-B

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Introduction

Bowie Seamount, which has a minimum depth of 24 m and is located approximately 175 km west of Haida Gwaii (Figure 1), is the shallowest and best-known seamount in Canada's Pacific Exclusive Economic Zone (EEZ). Initial research on the biology of Bowie Seamount, coupled with interest from the Haida Nation, led to Bowie Seamount and the adjacent Hodgkins and Davidson (also called Pierce or Peirce) Seamounts being designated in 2008 as the SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA), which is co-managed by the Government of Canada and the Council of the Haida Nation.

SK-B MPA consists of a single zone and one external boundary as described in the Bowie Seamount MPA regulations (SOR/2008-124[1]). For the purpose of fisheries management inside the MPA, three zones are defined in the Pacific Region Groundfish Integrated Fisheries Management Plan (DFO 2016) (Figure 2): Zone 1 covers the peak of Bowie Seamount to approximiately the 250 fathom (457 m) bathymetric contour, Zone 2 covers the rest of Bowie Seamount, and Zone 3 encompasses Hodgkins and Davidson Seamounts (DFO 2011).

In 2015, Fisheries and Oceans Canada (DFO) led a research survey (PAC 2015-48) to study the biology and oceanography of SK-B MPA. This report describes the collection of benthic imagery, plankton samples, hydro-acoustic data, CTD data, water samples, and seabird and marine mammal observations.

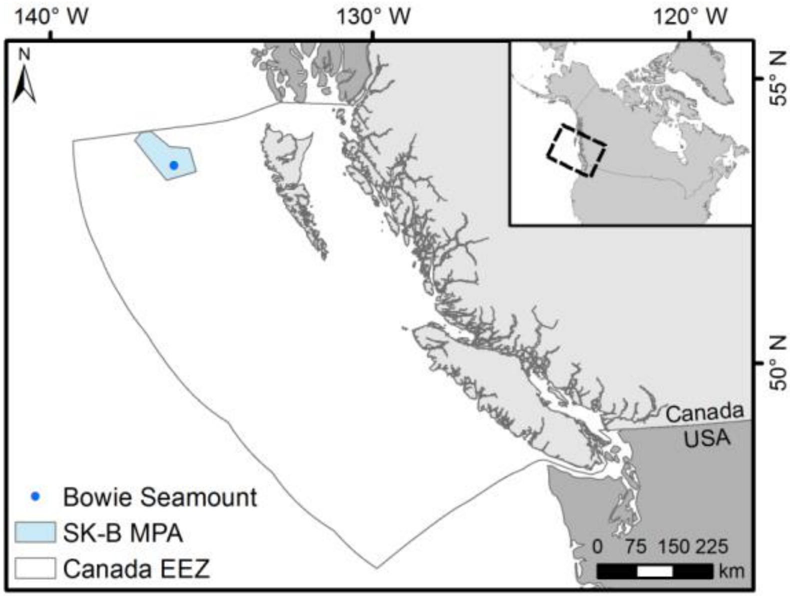

Figure 1. Location of Bowie Seamount and SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA) within Canada's EEZ (Exclusive Economic Zone).

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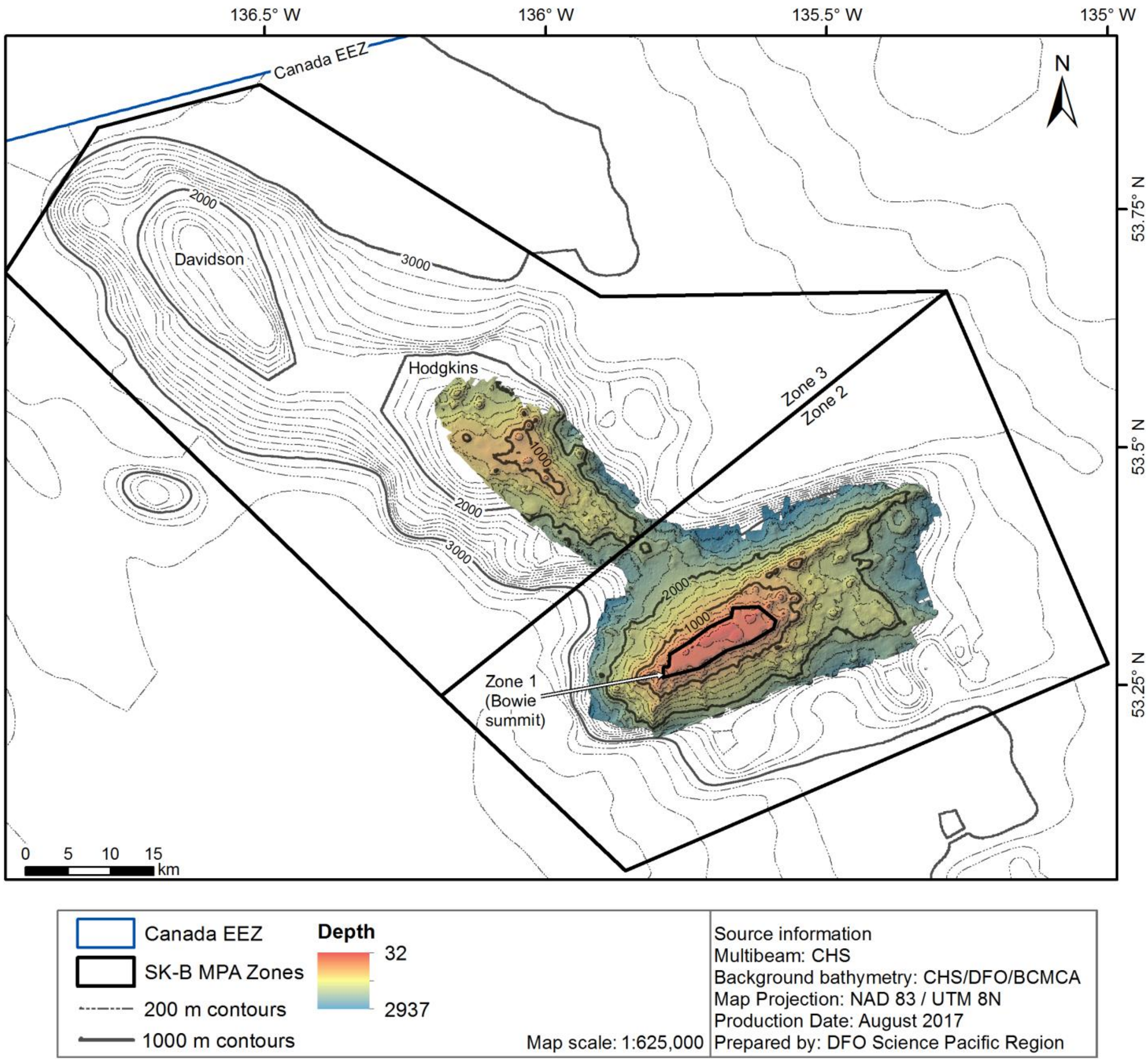
[1] http://laws-lois.justice.gc.ca/eng/regulations/SOR-2008-124/



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Previous Surveys

Sporadic surveys have taken place on Bowie Seamount since the 1940s for geological, biological, and naval purposes (Table 1). Information on fish and invertebrate species is available from commercial fishery records and from surveys carried out by SCUBA, submersible, and remotely operated vehicles (ROVs).

DFO carried out benthic video surveys in 2000 (PAC 2000-31; Yamanaka 2005) and in 2011 (PAC 2011-62; unpublished) (Figure 3). To meet its main objective of developing stock assessment methods for benthic rockfish, the 2000 survey collected video from a human occupied vehicle (Delta submersible; dive depths 53–306 m), conducted longline fishing experiments, and collected biological data on fish health and biological traits. Oceanographic sampling (CTD and bongo nets) and seabird and marine mammal observations were also carried out (Yamanaka 2005). The 2011 survey (led by James Boutillier, Pacific Biological Station, DFO) was a joint venture between DFO and the United States National Oceanic and Atmospheric Administration (NOAA) and aimed to document the habitats and species on Bowie Seamount; benthic imagery was collected using DFO's Phantom ROV (video and photos; 28–272 m) and NOAA's SeaBED AUV (photos; 180–933 m).

Little is known of the species composition and diversity in the deeper areas of SK-B MPA. With the exception of the deep AUV dives in 2011, all of the previous visual surveys of benthic communities at Bowie Seamount have been restricted to shallow areas around the plateau at depths less than about 300 m (Figure 3c). Prior to the 2015 survey described in this report, no visual surveys have been done anywhere on Hodgkins or Davidson Seamounts.

Physical Description and Geology

Bowie Seamount has an oblong shape oriented in the southwest - northeast direction, with a linear ridge extending approximately 20 km northeast from its northern end (Chaytor et al. 2007). The slopes of Bowie Seamount extend from a base depth of 2800 m to a flat summit plateau (area ~26 km^2) at depths of 200–250 m (Chaytor et al. 2007). Several pinnacles extend from an elevated area near the centre of the summit (Figure 2), with the tallest pinnacle rising to 24 m below the surface (Halcro 2000). Only Cobb Seamount, in international waters west of Washington State (USA), reaches comparable depths (26 m) among Northeast Pacific seamounts. The average slopes of Bowie Seamount are between 10 º and 20º, with more variable slopes (0–50º) along the southwest and northeast flanks (Chaytor et al. 2007).

Hodgkins Seamount is connected to Bowie Seamount to the northwest by a ridge about 2300 m deep. The summit of Hodgkins Seamount is more complex than that of Bowie Seamount, with at least 10 distinct pinnacles, the shallowest of which reaches 596 m. To the northwest of Hodgkins Seamount is Davidson Seamount, unofficially called Pierce or Peirce (*sic*) to avoid confusion with the more well-known Davidson seamount off California. Less information is available for Davidson Seamount than for Bowie and Hodgkins Seamounts, as no high-resolution bathymetry has been collected there. Davidson's summit is estimated to be between 1150 and 1500 m (Canessa et al. 2003, Manson 2009).

Bowie Seamount is the southernmost of 14 seamounts in the Kodiak-Bowie or Pratt-Welker Seamount Chain, which spans 1000 km from the Gulf of Alaska near Kodiak Island southeast to the Canadian waters west of Haida Gwaii (Turner et al. 1980, Chaytor et al. 2007). The seamounts in this chain increase in age to the northwest, but have an unresolved geologic history: they share characteristics of both "hotspot volcanoes", like the Hawaiian chain, and spreading-ridge seamounts, like many other seamounts in the Pacific Ocean (Turner et al. 1980, Canessa et al. 2003).

The majority of Bowie Seamount is at least 0.72 million years old (Turner et al. 1980), although volcanic activity may have occurred as recently as 18,000 years ago (Herzer 1971). The summit peaks likely formed from volcanic eruptions during the Late Wisconsin glacial period, when the top of Bowie Seamount was likely above sea level as a small island or shoal (Herzer 1971). Hodgkins and Davidson Seamounts are older, with estimates of 2.8 and 17.4 million years, respectively (Turner et al. 1980). Rock samples taken from the summit plateau of Bowie Seamount are mostly fine-grained alkali olivine basalts with vesicles, which are dark-coloured volcanic rock formed during rapid cooling of lava (Herzer 1971). Extrusive rock structures occur as pillow lavas, pillow fragments, volcanic bombs, tuffs, lapilli and ash (Herzer 1971). Shell fragments and rounded volcanic rock indicative of previous wave exposure are present on the summit peaks and the lower plateau (Herzer 1971).

Table 1. Previous biological surveys and analyses on Bowie Seamount, and related reports

Study	Survey year	Depths and method	Aim / Focus	Biological notes
1. Scrimger and Bird (1969)*	1969	Summit (SCUBA)	Scope instrument placement	11 benthic invertebrates identified
2. Herlinveaux (1971)	1969	27–37 m (SCUBA)	Oceanography, biological features	Abundant rockfish: Widow (*Sebastes entomelas*), Yelloweye (*S. ruberrimus)*, Redstripe (*S. proriger*)
3. Scagel (1970)*	1969	"	Identify algae from (2)	Algae found at ~30 m are taxa usually found in intertidal
4. Curtsinger (1996)	1995	To 50 m (SCUBA) To 150 (ROV) m	Exploration for National Geographic	- Shallow areas covered with seaweeds - Juvenile rockfish abundant above summit - Pacific Halibut, sea stars, scallops, and sea anemones common
5. Austin (1999)	1995	To 50 m (SCUBA) To 150 (ROV) m	Analysis of video from (4)	Summit had interesting mixture of shallow (California mussels and split frond kelp *Laminaria yezoensis*), deeper water (squat lobsters and prowfish), and oceanic species (salps).
6. Yamanaka and Brown (1999)	-	-	Collate species identified in fisheries reports and logs	~80 species of fish, invertebrates (mostly crabs), and mammals
7. Yamanaka (2005) PAC 2000-31	2000	53–306 m (submersible)	Survey benthic rockfish and habitat, evaluate catch rates, oceanography, seabirds and mammals	- More fish seen at Bowie Seamount than around Haida Gwaii - Rockfish dominate rocky habitats - Halibut, skates, sun stars and squat lobsters dominate the gravel slopes
8. McDaniel et al. (2003)	2003	To 40 m (SCUBA)	Document physical and biological features, list species	Summit had relatively low diversity relative to rocky subtidal of Haida Gwaii. - Recorded 18 taxa of algae, 83 invertebrates, and 12 fishes - Diverse seaweeds, with depth range extensions for most - Abundant rockfish, but did not observe the dense schools of large Widow Rockfish as reported by (2)
9. DFO-NOAA survey PAC 2011-62 (unpublished)	2011	28–272 m (ROV) 180–933 m (AUV)	Document habitats and species	Analyses currently underway.

* As described in Herlinveaux, 1971

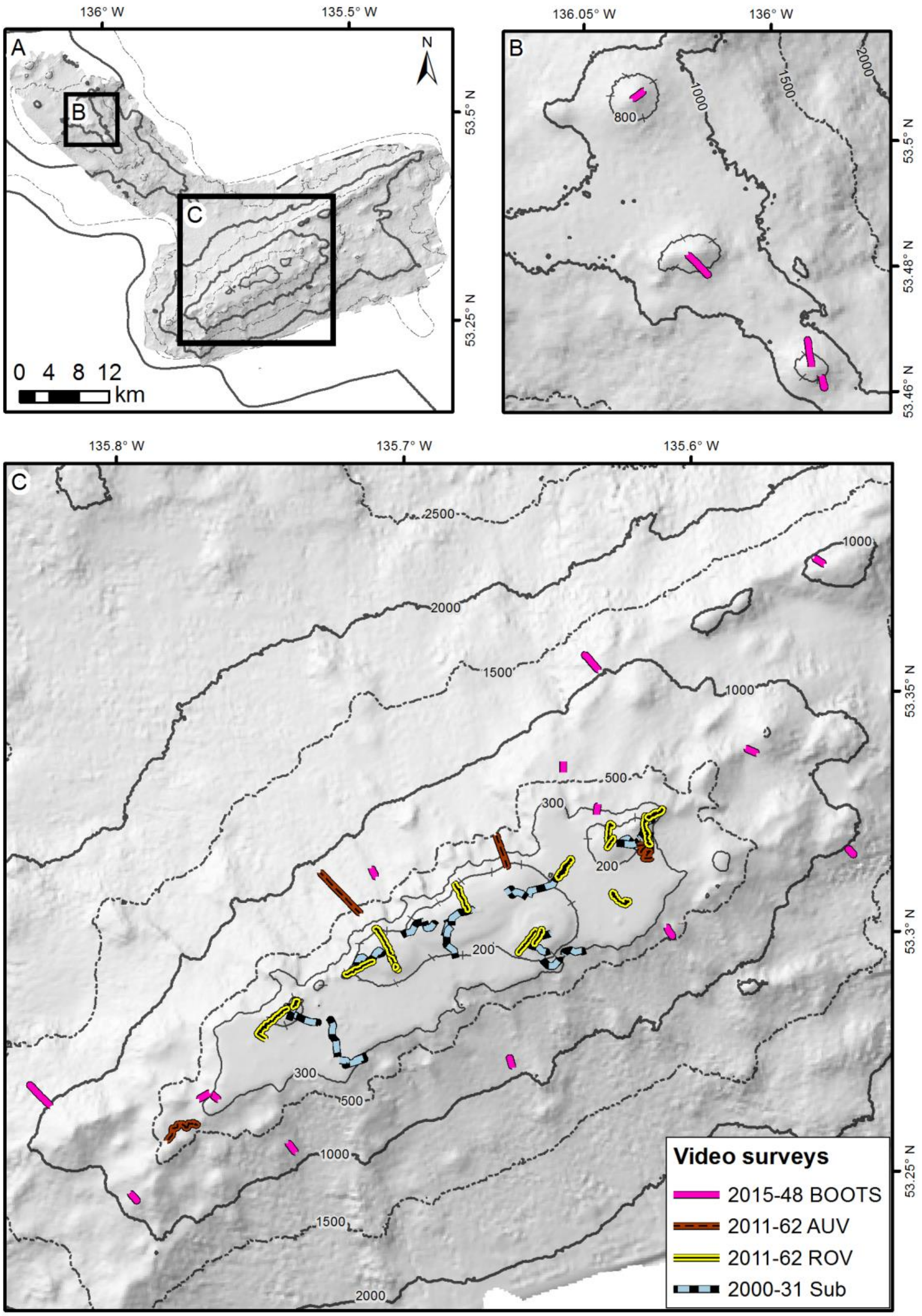

Figure 3. Locations of video surveys carried out by DFO at Bowie and Hodgkins Seamounts from 2000 (Delta submersible; Yamanaka 2005), 2011 (Phantom ROV and SeaBED AUV; unpublished), and 2015 (BOOTS tow-camera; this report); A) Bowie and Hodgkins Seamounts, B) the three summits of Hodgkins Seamount, and C) part of Bowie Seamount including the shallow summit.

Oceanography

The oceanography around Bowie Seamount and SK-B MPA is not well studied. Canessa et al. (2003) summarize available information on the climate, weather, and physical and chemical oceanographic conditions around Bowie Seamount.

Biology

There has been relatively little research on the benthic and demersal communities found on Bowie Seamount or within SK-B MPA. Lists of species present at Bowie Seamount have been compiled by Canessa (2003) and Rubidge et al. (unpublished) and a detailed inventory of benthic species observed or collected in previous expeditions and the survey described in this report can be found in Gauthier et al. (2018a,b,c).

Shallow-water Communities

Previous expeditions to collect biological samples and visual observations with submersible vehicles or SCUBA divers illustrate the diversity found in the shallower parts of the seamount (Table 1). McDaniel et al. (2003) provide the most recent and extensive description of the benthos around the seamount's summit, between about 24 and 40 m.

The summit of Bowie Seamount is characterized by clear waters, strong currents, and abundant and diverse red and brown seaweeds, particularly the flattened acid kelp (*Desmarestia ligulata*) (McDaniel et al. 2003). The rugose, complex, and fragile substratum provides habitats for many invertebrates, including molluscs, arthropods, cnidarians, echinoderms, sponges, and bryozoans (McDaniel et al. 2003). The strong currents appear to promote a dense and diverse filter- and suspension-feeding assemblage. Vertical surfaces are covered by a thick turf composed of bryozoans, zoanthids, encrusting sponges, hydroids, and calcareous tubeworms, with clusters of California mussels (*Mytilus californianus*) and giant barnacles (*Balanus nubilus*) found on rocky edges and covered with the encrusting turf species (McDaniel et al. 2003). Caprellid amphipods and brittle stars are common amongst the turf species, and anemones were common on steeper areas (McDaniel et al. 2003). Mobile species include an abundant and diverse assemblage of gastropods, including the large Oregon triton (*Fusitriton oregonensis*), a number of smaller snails, and six species of nudibranchs (McDaniel et al. 2003). McDaniel et al. (2003) observed relatively few decapods, although Austin (1999) saw squat lobsters (*Munida quadrispina*) in unusually large numbers given the shallow depth of water at the seamount. Sea stars (blood star *Henricia leviuscula* and leather star *Dermasterias imbricata*) are common (McDaniel et al. 2003). Scrimger and Bird (1969, in Canessa 2003) observed the white sea cucumber *Eupentacta (=Cucumaria) quinquesemita*, but no sea cucumbers were observed by McDaniel et al. (2003).

There are consistent reports of high densities of rockfish in shallow areas. Herlinveaux (1971) reported "layers of fish, 30 to 40 feet in depth were encountered on ascent and descent. […] the divers had to push fish out of the way to obtain photographs."

Seabirds and Marine Mammals

Little is known about the occurrence, abundance, or seasonal patterns of seabirds or marine mammals at Bowie Seamount and around SK-B MPA. At-sea bird surveys in the vicinity of Bowie Seamount in 1997, 1998, and 2000 (K. Morgan, pers. comm. in Canessa et al. 2003) recorded 13 species of bird[2] in summer and/or autumn, including Black-footed Albatross, Northern Fulmar, Murphy's Petrel, Sooty Shearwater, Buller's Shearwater, Fork-tailed Storm-Petrel, Leach's Storm-Petrel, Long-tailed Jaeger, Ancient Murrelet, Cassin's Auklet, Rhinoceros Auklet, Horned Puffin and Tufted Puffin. Glaucous-winged Gull and Black-legged Kittiwake were seen during winter. The seabirds may be attracted to the "seamount

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[2] All bird species names can be found in Appendix 9

effect" of Bowie Seamount, whereby surrounding eddies may contribute to locally increasing the abundance of plankton (Dower and Fee 1999). Previous marine mammal observations around Bowie Seamount include Sperm Whales (*Physeter catodon*), Killer Whales (*Orcinus orca*), Pacific White-sided Dolphins (*Lagenorhynchus obliquidens*), Northern Right Whale Dolphins (*Lissodelphis borealis*), Dall's Porpoises (*Phocoenoides dalli*) and possibly Striped Dolphins (*Stenella coeruleoalba*) (Canessa et al. 2003, Yamanaka 2005).

Fisheries

Early Fisheries (1950–1999)

Historically, fisheries at Bowie Seamount have been limited due to its distance offshore and potential for rough weather (Carter and Leaman 1981, 1982, Canessa et al. 2003). There has been occasional Pacific Halibut (*Hippoglossus stenolepsis*) fishing at Bowie Seamount since the 1950s (Canessa et al. 2003), however fishing records other than oral reports are not available prior to 1980 (Carter and Leaman 1981, Beamish and Neville 2002). Data collected since 1980 show limited Pacific Halibut fishing around Bowie Seamount with 63 metric tonnes (t) of catch from five boat landings in 1984 and 1992 (Canessa et al. 2003). The Japanese Sablefish (*Anopoploma fimbria*) fishery began fishing in Canadian waters in 1964 (McFarlane and Beamish 1983) and potentially fished at Bowie Seamount and other seamounts in the 1970s (Leaman et al. 1978, Canessa et al. 2003).

In 1980 and 1981, two exploratory fishing trips were conducted aboard the longliners *M/V Viking Star* and *M/V Star Wars II* to assess the potential for developing a rockfish (*Sebastes* spp.) fishery at Bowie Seamount (Carter and Leaman 1981, 1982). The fishers deployed 46 (28 in 1980 and 18 in 1981) longlines at depths of 45–600 m and 5 gillnets (1981 only) in the upper 100 m. Fishing was hampered on both trips by lost and damaged gear due to weather and poor charts for the area. Total retained catches were 11.5 t, composed primarily of Rougheye Rockfish (*Sebastes aleutianus*; 40%), Pacific Halibut (39%), Yelloweye Rockfish (*S. ruberrimus*; 10%*),* and Sablefish (8%). There were also 2.8 t of discarded catch, composed mostly of Pacific Halibut (59%).

Some exploratory mid-water trawls also took place in the early 1980s, with limited success (Canessa et al. 2003). In 1993, another exploratory trawl survey was conducted through a joint venture with the Deep Sea Trawlers Associations, DFO, and BC Ministry of Agriculture; landings were mostly Rougheye and Harlequin Rockfish (*S. variegatus*) (Canessa et al. 2003). Beginning in 1992, directed rockfish fishing was allowed on the seamount through a scientific permit that required vessels to carry onboard observers (Canessa et al. 2003). Between 1992 and 1999, there were occasional fishing trips to Bowie Seamount targeting rockfish with bottom longlines with hooks in the 200–500 m depth range (Beamish and Neville 2002, Canessa et al. 2003). The directed rockfish fishery was closed in 2000, after which time rockfish catch was only allowed as bycatch in the directed Sablefish fishery (Beamish and Neville 2002).

Canadian Sablefish longline trap fishery (1985-Present)

The Canadian bottom longline Sablefish trap fishery has operated at Bowie Seamount since 1985, and catch data are available since 1987 (Murie et al. 1996). Average annual Sablefish catches on the seamount have been approximately 100 t between 1987 and 2000 with a peak catch of 353 t in 1991 (Beamish and Neville 2002, DFO 2013). Between 1990 and 2001, there was an average of four trips to the seamount per year (Canessa et al. 2003). There have been occasional fishing trips to Hodgkins Seamount, with three reported trips from 1985 to 1992 (Murie et al. 1996).

Since the establishment of the MPA in 2008, the Sablefish trap fishery has been restricted to fishing in Zone 2, at depths below about 457 m on Bowie Seamount (DFO 2016). The Sablefish seamount fishery is currently divided into North and South areas that are managed separately from the coastal fishery. As of 2014, vessels are limited to 75,000 lb of Sablefish, 5000 lb of Rougheye Rockfish, and 1000 lb of other rockfish and flatfish species per trip (DFO 2016). In 2014 new interim management measures were adopted for the North area, reducing the allowable trips to Bowie Seamount to four per year (one vessel per month from May–August; DFO 2016).

The interim management measures include a coral and sponge bycatch sampling program, where vessels are required to carry an observer to collect coral and sponge bycatch data for at least half of the trips each year (DFO 2016). Biological samples collected during a 2014 fishing trip are described in Buchanan et al. (2015), and include a new species of glass sponge (*Doconesthes dustinchiversi;* Reiswig 2015). Trips with at-sea observers also deploy deepwater cameras and accelerometers on fishing gear, as part of a research program to monitor fishery-related impacts to sensitive benthic habitats. The program was initiated by the Canadian Sablefish Association in collaboration with Simon Fraser University and DFO in 2013 (Doherty and Cox 2017). Habitat mapping and the development of a sponge and coral encounter protocol for fishing in Zone 2 are underway (DFO 2016).

Other Fisheries

Albacore Tuna (*Thunnus alalunga*) fisheries have occasionally operated around Bowie Seamount, particularly in warm-water years (Canessa et al. 2003). There are records of two boats fishing for tuna at Bowie Seamount in 1980, and American vessels have reportedly traveled from Alaska to fish for tuna at Bowie Seamount (Canessa et al. 2003). The Albacore Tuna fishery uses trolling gear at depths near the surface and does not make contact with bottom habitats (DFO 2015b).

Threats to Biodiversity Within the MPA

A risk assessment carried out for SK-B MPA (DFO 2015a, Rubidge et al. unpublished) found that stressors related to oil spills, seismic surveys, aquatic invasive species, and fishing pose the greatest threats to the SK-B MPA ecosystem. Species and biogenic habitats most at risk include cold-water corals (Alcyonacea and bamboo coral *Isidella*), sponges, and Rougheye Rockfish.

Survey Objectives

The research objectives for the 2015 SG̲aan K̲inghlas-Bowie Seamount MPA survey were to:

1. Characterize the biodiversity, benthic community structure, and habitat in Zones 2 and 3 of SK-B MPA in response to a request for science advice from DFO's Oceans Program (RSIA# 2015OC01).
2. Contrast the planktonic community and chemical oceanography within and outside the boundaries of SK-B MPA in order to quantify the ecological and biological significance of seamounts within the MPA.
3. Collect opportunistic data on the seabird and marine mammal species occurrences within and outside the MPA boundaries and while in transit to and from the MPA.

General Methods

The 2015 Bowie Seamount survey (PAC 2015-48) was led by DFO aboard the *CCGS John P. Tully* from 4 to 20 July, 2015. The *Tully* departed the Institute of Ocean Sciences in Sidney, BC on 5 July, stopped in Port Hardy for fuelling 7–8 July, was stationed at SK-B MPA 10–17 July, and returned to Sidney on 20 July. The science crew included researchers from DFO (Pacific Biological Station and Institute of Ocean Sciences), Simon Fraser University, University of Victoria, and Environment Canada-Canadian Wildlife Service (Appendix 1). The Canada Coast Guard crew, led by Captain Michael Corfield, managed all operations aboard the ship and assisted with tow-camera operations, hydro-acoustic surveys, plankton tows, conductivity/temperature/depth (CTD) probe deployment, and seabird and marine mammal transects. Further details are available in the cruise plan[3] and cruise report[4] for PAC 2015-48. The sea conditions during the cruise are presented in Appendix 2.

The purpose of this report is to provide details on survey design, methodologies, data processing, and basic analyses of the benthic tow-camera, hydro-acoustic, plankton, CTD, seabird, and marine mammal surveys. These details serve as metadata for the survey, and a basis for more detailed analyses in the future.

Tow-Camera Surveys

BOOTS Tow-Camera System

BOOTS (Bathyal Ocean Observation and Televideo System) is a towed camera system named after James Boutillier, a DFO *emeritus* biologist. The original DFO concept design for BOOTS was modified and built by Highland Technologies, Inc. (Victoria, BC). BOOTS has a main metal frame to which all sub-sea instruments are attached, as well as a large rear fin (Figure 4A) that acts to align the system with the direction of current flow or tow direction during operations. The dimensions of the frame (height-width-length) are approximately 100 x 96 x 183 cm, with the total length including fin being approximately 288 cm. Its weight is approximately 363 kg (800 lb) and it has a depth rating of 2500 m.

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[3] https://www.waterproperties.ca/requests/cruiseplanview.php?cruiseid=2015-48

[4] https://www.waterproperties.ca/requests/cruisereportview.php?cruiseid=2015-48

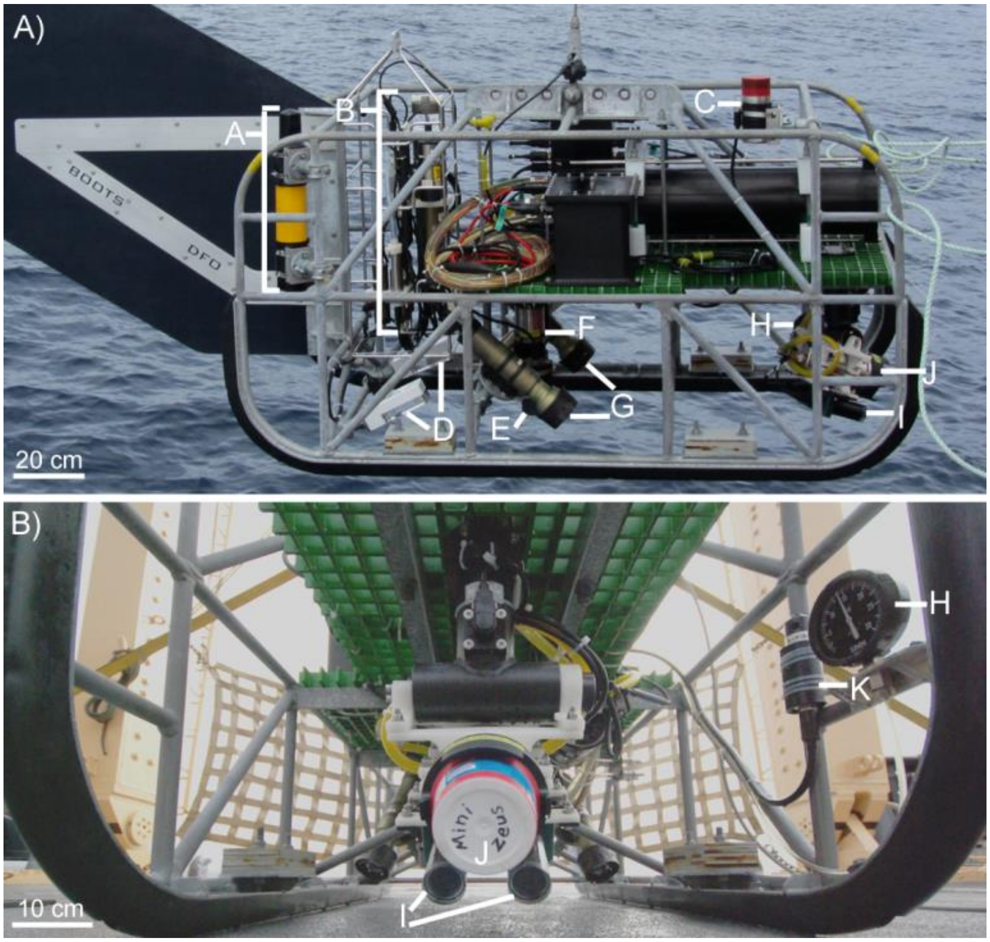

Figure 4. BOOTS tow-camera system equipment configuration during the 2015 survey. A) Side view during deployment, B) Front view while on deck. A: ultra-short baseline (USBL) transponder, B: Conductivity-temperature-depth (CTD) profiler, C: Sonar, D: light-emitting diode (LED) lights, E: altimeter, F: 1CamAlpha downward-facing camera, G: high-intensity discharge (HID) arclights, H: pressure compensator gauge, I: scaling lasers, J: MiniZeus forward-facing camera, K: secondary depth sensor. The positions of some instruments (lights and cameras) were adjusted over the course of dive operations to improve image quality. Photos by J. Curtis and K. Gale.

Mounted equipment and sensors

The equipment configuration used for the 2015 survey is shown in Figure 4. The positions of some instruments (lights and cameras) were adjusted over the course of dive operations to improve image quality, and will likely change for future surveys. A high-definition (HD) MiniZeus video camera (Insite Pacific Inc., Solana Beach, CA) was set in the forward-facing position, and was positioned on a pan and tilt chassis (Remote Ocean Systems, San Diego, CA) for rotation on horizontal and vertical axes, respectively. Two parallel scaling lasers (AGO Environmental, Sidney, BC), positioned 10 cm apart, were attached to the pan and tilt chassis, such that the laser dots always remained in the centre of view. An HD 1CamAlpha+ video camera (SubC Imaging, Clarenville, NL) with 24-megapixel still image capabilities was set in the downward-facing position on the tow-camera frame. There were no scaling lasers associated with the downward-facing camera during the survey.

Two high-intensity discharge (HID) arclights (Deep Sea Power and Light, San Diego, CA) were positioned behind the 1CamAlpha to provide lighting for both the 1CamAlpha and MiniZeus cameras. Two light-emitting diode (LED) lights (Remote Ocean Systems) were also positioned behind the 1CamAlpha to increase the amount of lighting in the downward-facing videos. The camera system was designed to have two hybrid LED strobes/lamps (SubC Imaging, Clarenville, NL) that could be triggered during still-image capture; however, the lamps were not available for the 2015 survey.

A Seabird SBE25 CTD was mounted in the rear-centre of the tow-camera frame and was equipped with an SBE 3plus temperature sensor, an SBE 43 dissolved oxygen sensor, an SBE 4C conductivity sensor, an SBE 29 pressure sensor, and an ECO-AFL/FL fluorometer. The pressure (depth) sensor was only rated to 1000 m, preventing CTD depth readings deeper than 1095 m (see Appendix 3).

An Imagnex 881A scanning sonar and an Imagenex 864 altimeter system (Imagenex Technology Corp., Port Coquitlam, BC) was used for navigation, to detect objects around the camera system, and to monitor the distance above the seafloor. These data were viewed in Imagenex software and recorded in a proprietary format that could be played back to view sonar images and altitude, but could not be extracted as data in text format.

An ultra-short baseline (USBL) broadband acoustic tracking system (BATS) (EdgeTech, West Wareham, MA), consisting of a transceiver and a transponder attached to the tow-camera frame, was used to track the tow-camera underwater. The transceiver was mounted on a pole that pivoted near the aft port bulwarks of the *Tully*. The pole was submerged during dives and removed from the water during transit. The relative USBL positioning data from the EdgeTech software Trackman was used by the hydrographic surveying program Hypack (Hypack, Inc., Middletown, CT) to calculate and view the position of the tow-camera in real time. Hypack integrated a number of data streams (ship and camera positioning, CTD, depth, pan and tilt, timestamp, and dive number) into a log file and into an overlay that was recorded onto some of the video streams.

Before each dive all instruments were time-synchronized using UTC time as a standard. The start and end times of all recordings (video, CTD, tracking, altimeter) were documented in a technical log. After the cruise, this log was used to manually align the timestamps of all videos in a lookup table to allow for synchronization of downward facing and forward facing video, and synchronization of the video with GPS tracking and CTD measurements.

Deck layout and dive operations

A detailed description of deck operations is found in Appendix 4. The BOOTS winch was mounted on F Pad on the *Tully*, facing 10.5 degrees inboard so it lined up with the centre of the A-frame. The BOOTS wire was routed through the BOOTS block on the A-Frame-mounted heave compensation system and connected to the top of the tow-camera frame. When not diving, BOOTS was secured on deck between the A-Frame, except during multi-net casts when it was moved forward and port.

During operations, a winch operator on deck communicated with the chief scientist in the lab by radio to let out or bring in the winch wire to control the ascent and descent of the tow-camera system. A remote monitor at the winch station allowed the operator to anticipate the need for payout and retrieval. The A-frame was let out during deployment to keep BOOTS away from the ship, and a passive heave compensation system helped reduce the effect of ocean swell on the movement of BOOTS (Figure 5).

At the beginning of a dive, BOOTS was lowered to about 20 m below the surface, system power was turned on, and all data logging, including video recording, was initiated. The camera system descended at 0.3 m/s to 100 m depth, at which time descent speed could increase to 0.4 or 0.5 m/s if conditions allowed (i.e., swell < 0.5 m). Once BOOTS reached 20–30 m above the seafloor, the onboard altimeter began receiving a signal. Using the altimeter, sonar, and visual confirmation from the two video feeds, BOOTS was lowered to within 3–5 m of the seafloor at 1–10 m increments. The forward-facing camera was used to check the compensator gauge for system pressure, then the pan and tilt was reset to an appropriate transect viewing angle at approximately 45º.

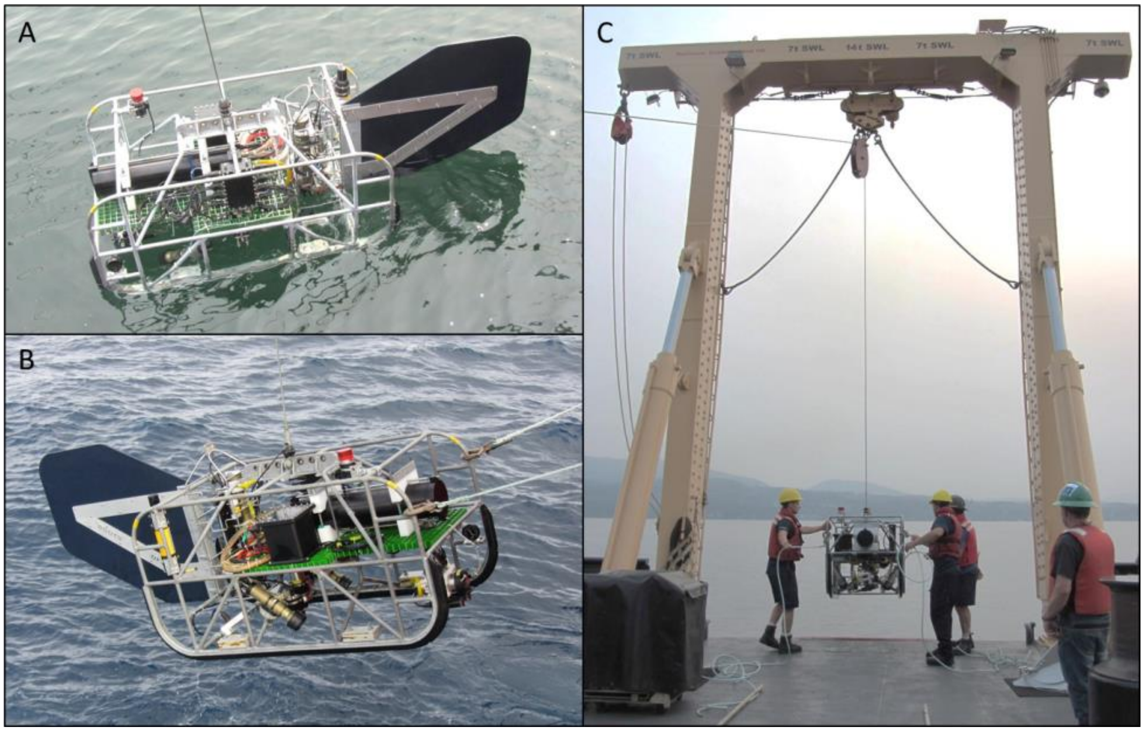

Figure 5. Deployment and recovery of the BOOTS tow-camera system. Stabilizing taglines are visible in B and C. Photos by J. Curtis.

The operation of the tow-camera system, including towing along transects, was managed through three-way communication among the chief scientist, bridge crew, and winch operator. Following a pre-transect check of the compensation gauge, transect heading and depth were selected in consultation between the chief scientist and bridge crew on the basis of slope, aspect, current flow, wind and surface conditions. Transects began with the ship moving between 0.2 and 0.3 knots along the chosen transect heading. The tow-camera did not begin to move as soon as the ship began moving; there was a lag as the camera system oriented to the current and began moving along the transect heading. Depending on survey objectives, terrain, and conditions, transect speed could potentially be increased to 0.4 knots; however, it is recommended to maintain a speed of 0.2 knots for collection of high quality images of benthic fauna. Throughout the entire dive (from BOOTS entering the water, through the transects and other bottom time, until recovery began), the chief scientist viewed the video, altimeter, and sonar feeds in real-time and called to the winch operator by radio to bring in or let out the cable at 0.5–1 m increments to keep BOOTS at a safe, but appropriate altitude for collecting images of the seafloor and associated fauna. Altitudes of approximately 2.5–3.5 m above the seafloor could be safely maintained when swell was less than 2 m; altitudes of 3.5–4.5 m were required when the swell exceeded 2.5 m.

During recovery, BOOTS was raised 10 m above the bottom while the compensator gauge was checked and the ship reoriented as needed. BOOTS was recovered at 0.4–0.5 m/s to 20 m depth, at which time the heave compensator was disengaged, the tow-camera system power was turned off, and the crew prepared to recover the system onto the deck (Figure 5).

This was the pilot survey for BOOTS, and as a result, several technical challenges were identified during testing and operations. Some technical challenges (e.g., communications with the Seabird SBE25 CTD) were resolved while at SK-B MPA, while others (e.g., lack of text-based data log from altimeter) remain on a list of recommendations for further refinement (Appendix 4).

Sampling Design

Potential sampling locations were identified on each of the three seamounts within SK-B MPA using the "stratified random" option of the "Sampling Design Tool" add-on for ArcMap 10 (Buja and Menza 2013). Strata were designated as 100 m depth bins between 400 and 1600 m (1400–1600 m at Davidson), split into four quadrants over each seamount. In the Sampling Design tool, the option "proportional" was chosen to place more points in strata with larger surface area, with manual adjustment of point allocation to ensure each stratum contained at least one point.

Based on data collected at Cobb Seamount (Curtis et al. 2015), Cherisse du Preez (DFO, Institute of Ocean Sciences) created a series of species distribution models to predict the presence and abundance of a number of coral taxa using depth and depth derivatives (e.g., slope, aspect, rugosity). Models for the orders Alcyonacea and Antipatharia were projected onto Bowie and Hodgkins Seamounts and combined into a single layer that predicted areas with (1) low probability of presence of both orders, (2) high probability of low density of both orders, or (3) high probability of high density of both orders. A pixel had to have a high probability of both coral orders to be recorded as "high probability"; if one order was modeled as "high probability" and the other "low probability" the pixel was recorded as "low probability". The point locations output from the Sampling Design Tool were manually adjusted to give a somewhat equal distribution in each of the three model categories, while maintaining the depth and quadrant stratification.

The initial potential sampling locations included 80 sites at Bowie Seamount, 31 sites at Hodgkins, and 12 sites at Davidson. As dive planning progressed, the deepest stations (deeper than 1200 m, including all sites at Davidson Seamount) were excluded from consideration for logistical reasons. Three random shallow stations (325–349 m) were created for the first test dives on Bowie Seamount, and three semi-random stations were identified to survey the three pinnacles of Hodgkins Seamount. On survey days, tow-camera survey start locations were chosen semi-systematically to span a range of depths and quadrants. However, limitations associated with time constraints, current ship position, transit times between sites, weather conditions (wind, swell, currents), CCG crew schedules, and technical/testing needs prevented implementation of a fully random-stratified design.

From each start location, a line 250 m long was drawn in ArcMap for the ship to move along. Generally, these lines ran perpendicular to depth contours (i.e., the camera moved straight upslope), but if there were logistical constraints regarding the ship's movement, such as when the transect would require moving parallel to prevailing currents, the line was re-drawn in consultation with bridge crew. Moving upslope was preferred because it maximized the quality of lit seafloor in the video for navigation (i.e., obstacles could be more easily anticipated and avoided) as well as for post-cruise analysis. Moving downslope reduced the video quality because the cameras were higher than the rest of the frame, and it was much more difficult to monitor the rear of the frame and prevent physical contact with the seafloor or associated fauna.

Collection of Imagery Data

High definition video

HD video from the MiniZeus and 1CamAlpha cameras was collected continuously from the time the camera system was powered on (~20 m depth) until it was retrieved. For each dive, the HD video was archived as a series of shorter video clips (MiniZeus: 00:05:43 each, 1CamAlpha: 00:17:01 each; individual file size limited to 2 GB). The MiniZeus HD video was recorded using a Digital Rapids StreamZ encoding system, with concurrent recording onto solid state drives using a Black Magic Hyperdeck Studio video recorder. A standard definition (SD) feed of the 1CamAlpha video was transmitted into the lab and, when the seafloor was visible, was recorded using a FireStore FS-2E disk recorder. Dive name, position, and time were hard-coded onto the HD MiniZeus video and the SD 1CamAlpha video with an overlay (Videologix Proteus II). The HD 1CamAlpha videos and still images were recorded internally on the camera and received no overlay information. Timestamps for the 1CamAlpha imagery were stored as subtitle files for the video and as EXIF data for the photos.

Prior to detailed annotation, each of these clips was viewed and classified according to the stage of the dive: descent, on bottom, transect, transiting, ascent. Within each dive (i.e., each time BOOTS left the deck and was recovered) there could be one or more transects. The transiting category was used when the camera was raised from the seafloor, moved mid-water, and lowered back down (e.g., Dive 19).

About 42 hours of forward-facing HD video (MiniZeus, 17 dives) and about 38 hours of downward-facing HD video (1CamAlpha, 16 dives; 1 dive did not record) were collected. Of the downward-facing video, about 13 hours was initially considered bottom time and was also recorded as an SD feed. Seventeen transects consisting of approximately 12.5 hours of seafloor video were analyzed for the identification, distribution, and habitat of benthic species (Table 4). Transects were completed for Dives 5–20 (Dive 19 included two transects, a and b); video from the Dive 4, a test dive, contained no transect and was not analyzed. The remaining video was either stationary on the bottom, transiting, or captured the water column during descent and ascent. The descent/ascent video will be analyzed for zooplankton identification at a later date.

Photographs

High resolution photographs (6544 x 3680 pixels) were collected using the 1CamAlpha during 16 of the 17 BOOTS dives. The camera was configured to automatically take a photo every 10 seconds, with the intention of obtaining equally-spaced (but not necessarily overlapping) images of the seafloor. However, the actual interval between captured pictures was about 15 seconds (average 4 pictures per minute). Overall, 3546 photos were collected during the BOOTS dives.

Annotation of Tow-Camera Video

Software

Video Miner (DFO; v. 2.1.3 and 2.1.4) custom video annotation software was used to annotate the transect-mode video clips from the forward-facing MiniZeus camera (see Appendix 5). Video Miner displays video or still images in a player window and populates a Microsoft Access database with time-tagged entries. For video, the time is calculated from frame counts by the software after calibrating it with the time displayed in the video overlay. For still images, the time and date is extracted from the EXIF data. Because all tow-camera system data were time synchronized, the time tagged data could be merged with the tracking data so that the coordinates and depth could be determined for any observation.

New fields and data types can be modified or added as necessary for different projects in Video Miner. The software enters data into a single database table. Most of the data are controlled by look-up tables that comprise standard codes used across multiple DFO projects (species codes, substrate codes, etc., but these codes can vary among programs). The software interface has three general areas for entering data. The first area refers to header information where data such as date, time, project, and transect are specified. The header information is recorded once at the beginning of a video/dive/transect and then copied automatically in following records. The second area has programmable buttons that enter data into a database field from a look-up table. This is the “habitat data” panel and is often used for recording habitat characteristics such as substrate type and complexity; however, it can also be used for other data like image quality and survey mode. The third area is the species description area, which contains programmable buttons that enter species codes from a look-up table. The user can also enter data about that entry like confidence level, number of species, lengths, widths, or comments.

The video was viewed at a playback rate of 1.0x (normal speed). At 10 s intervals, information on survey mode, video quality, habitat and species was annotated based on visible organisms and seafloor features. Habitat and species data were annotated only when the image quality was sufficient and the BOOTS tow-camera system was "On bottom" or in "Transect" survey mode.

Image quality depended on water quality, camera angle, lighting configuration, distance from the seafloor, and technical difficulties. The image quality categories and codes used to annotate the video are listed in Appendix 5.

During annotation, the tow-camera was considered "Off bottom" if it was high enough that it was impossible to see the seafloor or to identify animals, or if the image quality was poor (e.g., poor lighting or high density of particulates in the water). For each 10 s of video, survey mode was classified according to whether the tow-camera was following the transect line in a smooth and continuous manner (transect mode), stopped, slowed, or turned (investigation mode). Only organisms visible on or near the seafloor that were large enough to be detected and resolved when the tow-camera was in "transect" mode were annotated and were included in an inventory of species observed within the MPA (Gauthier et al. 2018a,b,c).

Field of View and Transect Area

Field of view and transect area was not calculated for this report. Laser dots for scaling were not present in the video or photos collected with the 1CamAlpha camera, as there were no downward-facing lasers installed on the tow-camera system. Although there were lasers on the forward-facing camera, the failure of one laser during Dive 12 led to scaling dots being available only for about half of the dives. Because the swell caused the tow-camera system to be constantly moving up and down, it was impossible to measure the width of field of view consistently throughout the survey.

Annotation of ROV photos

A total of 3546 photos were taken on 16 of the 17 dives (the 1CamAlpha was not used on Dive 4), with 112–611 photos taken per dive. Due to the fact that the planned LED strobes were not available for the survey, the low light levels resulted in photos that were only slightly better quality than could be obtained from video screen grabs and were only used to verify species identification and counts if needed.

Species identification

We examined all forward-facing video collected during the 2015 survey to produce a photo-documented species inventory list (Gauthier et al. 2018a,b,c), and to aid with future species identifications. We identified species primarily on the basis of their appearance, depth range, and behaviour as documented in photographs and video. We drew on a compilation of published species checklists from Bowie Seamount (e.g., Table 1), expert knowledge, and a range of taxonomic references to identify organisms to the lowest taxonomic level given available evidence (Gauthier et al. 2018a,b,c). We based our nomenclature on the phylogeny outlined in the World Register of Marine Species database (WoRMS Editorial Board 2017).

There are challenges associated with identifying small and rare taxa using only imagery. Confidence in identification of species was affected by various factors including water clarity, image quality, distance between the camera and biota, the angle and lighting, the size of the species, and the lack of unique features. The lowest taxonomic level of organisms was provided during video annotation taking all these factors into account while keeping a high level of confidence. For example, if no distinguishing features of a rockfish were visible we recorded “*Sebastes* spp.” or, the case of thornyheads, “*Sebastolobus* spp.” in deeper areas (>500m) (Cherisse Du Preez, pers. comm.).

Another pair of species, Rougheye Rockfish *(Sebastes aleutianus)* and Blackspotted Rockfish (*Sebastes melanostictus)* was recorded as the “Rougheye complex” in annotation. These species have very similar morphologies but differ slightly in colouration (Love et al. 2002, Orr and Hawkins 2008, Butler et al. 2012), and are known to hybridize (Orr and Hawkins 2008). Thus, the species are difficult to distinguish from images alone (Du Preez et al. 2015). Very small organisms (< 5 cm) and those far from the camera with no distinguishable feature were generally impossible to identify at the phylum level and were ignored. For example, a small white organism could be a small sponge (or fragment), a small anemone, or a small white gastropod. The inability to stop to take close-up imagery or take samples is a limitation of the tow-camera system for video surveys.

Species abundance

Individual organisms were counted along the transects. When groups of organisms were too abundant to count individually, relative abundance was estimated if video quality allowed (Table 2, as defined by Curtis et al. 2015). Taxa for which relative abundance was estimated included squat lobsters (*Munida quadrispina*), gastropods, fragile pink sea urchin (*Strongylocentrotus fragilis*), crinoids, lattice-skin sponge (*Farrea* sp.), bryozoans, white and beige encrusting sponges, and *Esperiopsis* sp. sponge. Organisms occurring at the periphery of the video often were not clear enough to count or identify.

Table 2. Species relative abundance categories and definitions. Category definitions for colonial animals are based on Nelson et al. (2011) and species relative abundance categories were defined by Curtis et al. (2015).

Category	**Non-colonial organisms**	**Colonial organisms**
Abundant	>8 individuals	>25 % cover
Frequent	2–7 individuals	5–25 % cover
Rare	1 individual	<5% cover

Habitat classification

Habitats observed in the forward-facing video were classified according to substrate type and the degree of relief. For each 10 s section of transect video, the percent cover of the dominant and subdominant substrates was estimated and recorded. Fourteen codes, including wood, bedrock, cobble, gravel, sand, shell, mud, shell, and sponge, were used to classify dominant and subdominant substrate types (Appendix 5). Habitat codes used by DFO in a broad range of projects were adapted by Curtis et al. (2015) from the Wentworth Scale (Wentworth 1922). Percent cover of dominant and subdominant substrates was categorized according to five ranges as outlined in Appendix 5. Habitats were also classified according to the degree of relief, as defined by the four categories: (1) flat or rolling, (2) vertical relief between 0.5 and 2 m, (3) vertical relief, or (4) slope or wall (Curtis et al. 2015).

Potential disturbance to the seafloor

Evidence of potential disturbance to the seafloor was annotated for the video transects. When observed, disturbance level from possible fishing-related impacts (Table 3) was noted under the Video Miner habitat description. Comments were added for “dragging signs”, and for “dead” or “damaged” coral and sponge depending on physical appearance (see Appendix 6 for examples).

Table 3. VideoMiner disturbance categories.

DisturbanceId	Label	Disturbance Description
0	Absent	No evidence of disturbance
1	Light	>0–9% of biota and/or substrate showed evidence of disturbance
2	Moderate	10–50% of biota and/or substrate showed evidence of disturbance

Results: Tow-Camera Surveys

Seventeen tow-camera dives covering approximately 5.8 km were carried out at depths of 249–1246 m (Figure 6) at Bowie and Hodgkins Seamounts, increasing the total depth range of imagery surveys carried out at SK-B since 2000 (Figure 7). A detailed summary of the dives is given in Table 4.

Dives 4–16 and 20 took place on Bowie Seamount and Dives 17–19 were carried out on Hodgkins Seamount. Dives 1–3 were early test dives not used for any analyses. Dive 4 at site Bow-085 was also a test dive; although images and other data were collected during this dive, no transect was carried out and site Bow-085 was later surveyed in Dive 13. The 17 dives included 17 transects (no transects during Dive 4 and two transects, a and b, during Dive 19).

Species observations

Overall, 124 taxa from 51 families, 30 orders, 16 classes, and 10 phyla, including morphotypes and putative and unidentified species, were identified from analysis of benthic video taken from the forward-facing camera (Table 5). This brings the total number of taxa observed and/or collected from Bowie Seamount to 341 taxa from 15 phyla (Gauthier et al. 2018a,b,c). Analysis of the benthic community in SK-B MPA is ongoing and is not presented here.

CTD data and positioning

Processing details for the tow-camera CTD and positioning data is available in Appendices 3 and 7, and plots of CTD depth, temperature, salinity, and dissolved oxygen for each dive are presented in Appendix 8. Due to technical difficulties, the tow-camera CTD data were available for only 10 of 17 dives. Similarly, high-quality USBL positioning was only available for 11 of 17 dives; the ship's A-frame (stern) position was used for the remaining 6 dives.

Potential disturbance to the seafloor

We observed 20 video clips in seven dives with a "light" level of disturbance, and seven video clips in two dives with a "moderate" level of disturbance (Appendix 6). No fishing gear (nets, lines, or traps) was observed. Four "dragging signs" comments in two dives were made; however, it should be noted that dragging signs tend to be more visible in the presence of soft bottom and are less visible on video imagery compared to scanning sonar imagery (De Leo et al. 2017). Three "damaged corals", 19 "dead coral", and 11 "dead sponges" were recorded, although the cause of death or damage is unknown.

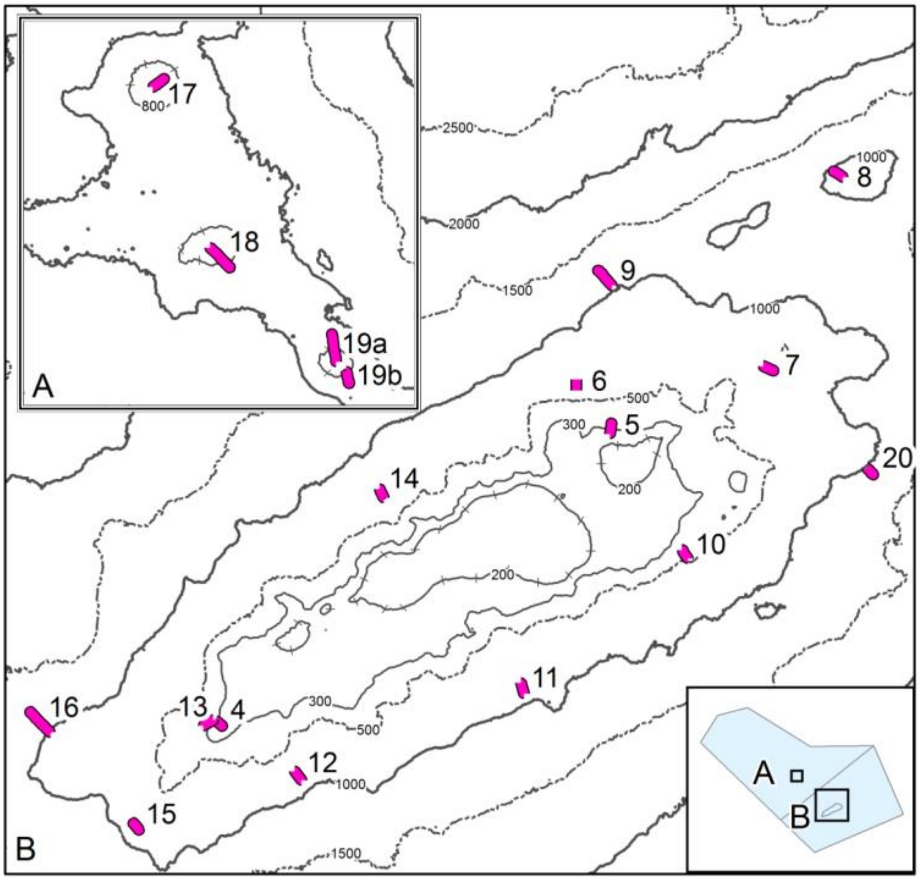

Figure 6. Tow-camera transects carried out during cruise PAC 2015-48 on A) Hodgkins Seamount, and B) Bowie Seamount. Inset shows locations of surveys within SK-B MPA boundaries. Contour line depths shown in m.

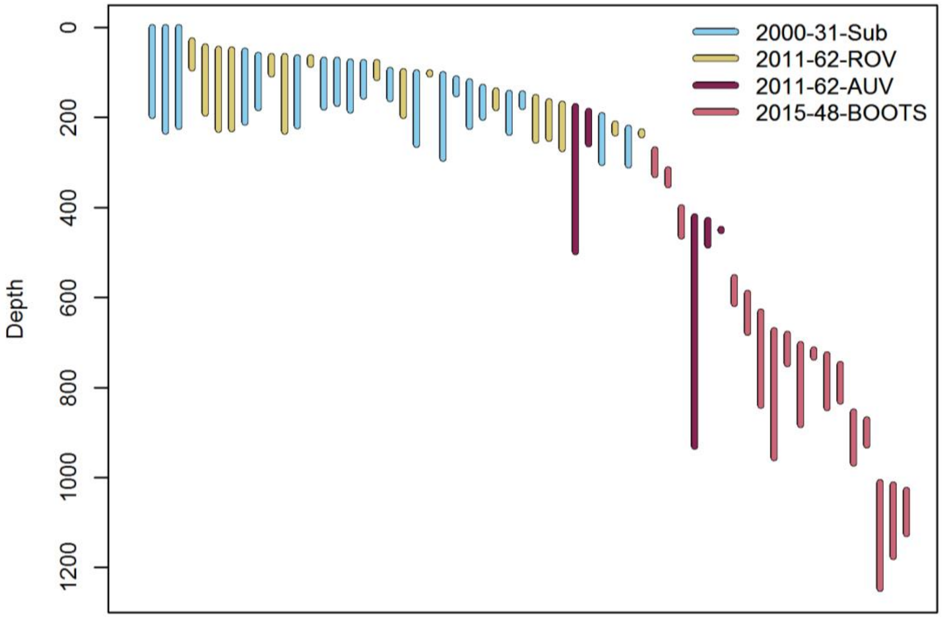

Figure 7. Distribtion of depths surveyed at Bowie and Hodgkins Seamounts in imagery surveys in 2000 (submersible), 2011 (remotely operated vehicle and autonomous underwater vehicle), and 2015 (tow-camera). Depth range for each transect (individual lines) from Gauthier et al. (2018a,b,c).

Table 4. Summary of BOOTS tow-camera dives. Dive duration is the time elapsed between the beginning of deployment (when instruments started recording at ~ 20 m below surface) and the end of recovery (when instruments were powered off at ~ 10 m below surface) for each dive. Start and end locations are the coordinates of the ship's A-frame (stern) at deployment and recovery. Transect depth, duration, and length were determined using the timestamps "transect begin" and "transect end" for each dive, and generally correspond to time on the bottom while moving. Depth source indicates if depth data were obtained from the CTD, from the tow-camera system pressure sensor, or from a combination of the two (see Appendix 3). CTD indicates if there were CTD data available for the entirety of the dive. USBL indicates if there was camera location tracking available for the entirety of the dive (Yes) or if the ship's A-frame coordinates were used (–). The transect length was determined by calculating the cumulative sum of the distance between consecutive coordinates. Dives 1–3 (not shown) were early test dives. Dive 4 was the first test dive at Bowie Seamount; although images are available from this dive, no transect was followed and the site was later surveyed in Dive 13.

Dive	**Site name**	**Date (Time)**	**Dive duration (H:M:S)**	**Transect duration (H:M:S)**	**Transect depth (m) (min-max)**	**Depth source**	**CTD**	**USBL**	**Start position**	**End position**	**Transect length (m) USBL/A-frame**
4	Bow-085	10 Jul	2:26:04	–	249–291*	CTD	Yes	–	53.263652, -135.762326	53.264638, -135.764281	Test dive
5	Bow-084	10 Jul	1:18:02	0:30:27	272–327	CTD	Yes	–	53.32595, -135.631375	53.32362, -135.631833	—— / 247
6	Bow-058	10 Jul	1:40:18	0:31:21	556–613	CTD	Yes	–	53.334813, -135.643469	53.332417, -135.643477	—— / 256
7	Bow-008	11 Jul	2:19:16	0:43:00	716–733	CTD	Yes	Yes	53.336859, -135.576151	53.337754, -135.580048	261 / 257
8	Bow-047	11 Jul	2:24:22	0:45:24	854–968	CTD	Yes	Yes	53.377443, -135.556861	53.376241, -135.553487	265 / 261
9	Bow-003	12 Jul	3:20:52	0:56:28	1016–1176	BOOTS	–	Yes	53.356611, -135.636769	53.353329, -135.63135	606 / 526
10	Bow-072	12 Jul	1:32:16	0:32:01	401–463	BOOTS	–	Yes	53.298638, -135.605073	53.300487, -135.607402	263 / 264
11	Bow-064	12 Jul	2:14:58	0:28:51	871–928	BOOTS	–	–	53.270932, -135.660308	53.273347, -135.66146	—— / 258
12	Bow-063	12 Jul	3:33:26	0:42:58	727–845	BOOTS	–	–	53.252868, -135.735367	53.252844, -135.735336	—— / 266
13	Bow-085	13 Jul	1:24:35	0:42:41	316–350	BOOTS	–	–	53.264891, -135.765488	53.263709, -135.768919	—— / 266
14	Bow-059	13 Jul	2:07:42	0:32:38	682–747	BOOTS	–	Yes	53.312264, -135.709998	53.309794, -135.708041	241 / 257
15	Bow-034	13 Jul	2:17:11	0:43:40	749–830	BOOTS	–	Yes	53.242381, -135.789635	53.244072, -135.792482	313 / 271

Dive	Site name	Date (Time)	Dive duration (H:M:S)	Transect duration (H:M:S)	Transect depth (m) (min-max)	Depth source	CTD	USBL	Start position	End position	Transect length (m) USBL/A-frame
16	Bow-013	13 Jul	3:36:55	1:24:39	1011–1246	CTD+ BOOTS	Yes	Yes	53.266406, -135.827851	53.262197, -135.820282	835 / 710
17	Hod-008	16 Jul	1:48:02	0:38:30	591–677	CTD	Yes	Yes	53.507547, -136.033855	53.506065, -136.037061	262 / 263
18	Hod-021b	16 Jul	2:30:19	1:09:55	632–840	CTD	Yes	Yes	53.478244, -136.015740	53.481357, -136.021436	559 / 515
19a*	Hod-033	16 Jul	4:20:25	1:08:40	674–956	CTD	Yes	Yes	53.468266, -135.988901	53.460334, -135.94201	534 / 511
19b*	Hod-033	16 Jul	“	0:29:13	704–882	CTD	Yes	Yes	53.460355, -135.984180	53.462569, -135.985231	375 / 251
20	Bow-010	17 Jul	2:40:32	0:30:56	1028–1125	CTD+ BOOTS	Yes	Yes	53.315836, -135.542645	53.317805, -135.544764	270 / 251
Total			**49:57:45**	**12:31:22**	**249–1246**						**—— / 5806**

*Dive 19 was split into two transects: after the first transect, the camera transited to a new station without recovery and without stopping instrument recording.

Table 5. List of taxa observed in tow-camera surveys at Bowie and Hodgkins Seamounts during PAC 2015-48. N = number of observations of each taxon.

Phylum	**Class**	**Order**	**Family**	**Scientific Name**	**Morphotype or Notes**	**N**	**Dive numbers**	**Depths (m)**
Annelida	Polychaeta	Sabellida	Serpulidae	Serpulidae		199	7–9, 16	721–1239
Arthropoda	Malacostraca	Decapoda		Decapoda		187	6–9, 12, 14–19	582–1210
Arthropoda	Malacostraca	Decapoda		Dendrobranchiata		13	8, 9, 11, 19, 20	677–1123
Arthropoda	Malacostraca	Decapoda	Chirostylidae	Chirostylidae	Possibly *Chorilia longipes*	98	7, 8, 12, 15, 17–19	657–958
Arthropoda	Malacostraca	Decapoda	Lithodidae	Lithodidae		7	5, 12, 14, 17, 18	319–770
Arthropoda	Malacostraca	Decapoda	Lithodidae	Lithodidae	Possibly *Paralithodes camtschaticus*	1	5	317–317
Arthropoda	Malacostraca	Decapoda	Munididae	*Munida quadrispina*		147	5–7	264–728
Arthropoda	Malacostraca	Decapoda	Munidopsidae	*Munidopsis quadrata*		771	8, 9, 11–13, 15–19	338–1100
Arthropoda	Malacostraca	Decapoda	Oregoniidae	*Chionoecetes*		18	7, 14, 16, 18, 19	674–1133
Arthropoda	Malacostraca	Decapoda	Oregoniidae	*Chionoecetes tanneri*		8	5, 7, 9, 11, 14, 19	309–1020
Brachiopoda				Brachiopoda		3	7	722–730
Chordata	Actinopteri			Actinopteri		22	9, 11, 12, 14–16, 18	650–1232
Chordata	Actinopteri	Gadiformes	Macrouridae	Macrouridae		20	8, 12, 16, 18, 20	760–1159
Chordata	Actinopteri	Gadiformes	Macrouridae	Macrouridae	Pacific or Abyssal grenadier	22	7–9, 11, 16, 18–20	730–1134
Chordata	Actinopteri	Gadiformes	Macrouridae	Macrouridae	Possibly Giant grenadier	58	7–9, 11, 15–17, 19, 20	665–1224
Chordata	Actinopteri	Perciformes	Zoarcidae	Zoarcidae		8	6, 15	580–805
Chordata	Actinopteri	Pleuronectiformes		Pleuronectiformes		5	5, 13, 14, 20	327–1094
Chordata	Actinopteri	Pleuronectiformes	Pleuronectidae	*Glyptocephalus zachirus*		1	10	411–411
Chordata	Actinopteri	Pleuronectiformes	Pleuronectidae	Pleuronectidae	Dover or Deep-sea Sole	60	5–7, 9–14, 16–20	272–1173
Chordata	Actinopteri	Scorpaeniformes	Agonidae	*Xeneretmus latifrons*		8	5	273–324
Chordata	Actinopteri	Scorpaeniformes	Anoplopomatidae	*Anoplopoma fimbria*		1	11	906–906
Chordata	Actinopteri	Scorpaeniformes	Scorpaenidae	Scorpaenidae		76	5, 10, 13	269–448
Chordata	Actinopteri	Scorpaeniformes	Sebastidae	*Sebastes* sp.		45	5, 10, 13	325–458

Phylum	Class	Order	Family	Scientific Name	Morphotype or Notes	N	Dive numbers	Depths (m)
Chordata	Actinopteri	Scorpaeniformes	Sebastidae	*Sebastes melanostictus*		16	5, 10	304–449
Chordata	Actinopteri	Scorpaeniformes	Sebastidae	*Sebastes ruberrimus*		1	5	326–326
Chordata	Actinopteri	Scorpaeniformes	Sebastidae	*Sebastes variegatus*		1	5	327–327
Chordata	Actinopteri	Scorpaeniformes	Sebastidae	*Sebastolobus* sp.		666	5–20	306–1173
Chordata	Thaliacea	Salpida		Salpida		1	14	739–739
Cnidaria				Cnidaria	Possibly Octocorallia	2	7, 12	723–735
Cnidaria	Anthozoa			Anthozoa		1	12	740–740
Cnidaria	Anthozoa			Anthozoa	Bushy white coral	2	12	832–837
Cnidaria	Anthozoa			Octocorallia		6	7, 12	724–824
Cnidaria	Anthozoa	Actiniaria		Actiniaria		118	5–20	281–1213
Cnidaria	Anthozoa	Actiniaria		Actiniaria	Pink anemone	7	15, 16	790–1239
Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Cribrinopsis* sp.	Possibly *Cribrinopsis fernaldi*	1	6	565–565
Cnidaria	Anthozoa	Actiniaria	Actinostolidae	Actinostolidae		80	6–12, 14, 15, 17–20	413–1123
Cnidaria	Anthozoa	Actiniaria	Hormathiidae	Hormathiidae		31	10, 13	336–435
Cnidaria	Anthozoa	Actiniaria	Liponematidae	*Liponema brevicorne*		32	10, 13	330–413
Cnidaria	Anthozoa	Alcyonacea		Alcyonacea		224	7–10, 12–15, 17–20	331–1160
Cnidaria	Anthozoa	Alcyonacea		Alcyonacea	Possibly Octocorallia	1	12	784–784
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae	*Anthomastus* sp.		43	8, 9, 12, 16, 18–20	738–1201
Cnidaria	Anthozoa	Alcyonacea	Isididae	Isididae		71	7, 9, 12, 13, 15–20	330–1239
Cnidaria	Anthozoa	Alcyonacea	Isididae	*Lepidisis* sp.		10	9, 12, 16, 20	816–1169
Cnidaria	Anthozoa	Alcyonacea	Paragorgiidae	*Paragorgia* sp.		44	7, 8, 12, 17–19	653–960
Cnidaria	Anthozoa	Alcyonacea	Paragorgiidae	*Paragorgia arborea*		1	19	863–863
Cnidaria	Anthozoa	Alcyonacea	Plexauridae	*Swiftia* sp.		81	7–9, 12, 14–16, 18, 19	685–1194
Cnidaria	Anthozoa	Alcyonacea	Plexauridae	*Swiftia simplex*		2	12	781–809
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	*Narella* sp.		2	16	1211–1237
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	*Primnoa pacifica*		34	7, 13	330–731

Phylum	**Class**	**Order**	**Family**	**Scientific Name**	**Morphotype or Notes**	**N**	**Dive numbers**	**Depths (m)**
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Primnoidae	Possibly *Parastenella* sp.	23	8, 12, 18, 19	776–952
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Primnoidae		370	7–10, 12, 13, 18, 19	328–1173
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Primnoidae	Primnoid sp. 1 (yellow)	50	19	823–927
Cnidaria	Anthozoa	Antipatharia		Antipatharia		16	8, 15, 18, 19	738–966
Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Lillipathes* sp.		28	12, 19	775–942
Cnidaria	Anthozoa	Pennatulacea		Pennatulacea		10	7, 9, 12, 14	693–1051
Cnidaria	Anthozoa	Pennatulacea	Anthoptilidae	*Anthoptilum grandiflorum*		4	6, 14, 16	591–1096
Cnidaria	Anthozoa	Pennatulacea	Halipteridae	*Halipteris* sp.		47	5, 6, 9, 10, 14	276–1047
Cnidaria	Anthozoa	Pennatulacea	Umbellulidae	*Umbellula* sp.	Possibly *Umbellula lindahli*	2	9, 14	704–1035
Cnidaria	Hydrozoa	Anthoathecata	Oceaniidae	*Turritopsis* sp.	Actiniaria sp. 1	11	7, 10, 18, 19	416–922
Cnidaria	Hydrozoa	Anthoathecata	Oceaniidae	*Turritopsis* sp.	Actiniaria sp. 2	89	6–10, 15–20	425–1225
Cnidaria	Hydrozoa	Anthoathecata	Oceaniidae	*Turritopsis* sp.	Actiniaria sp. 3	4	7	723–732
Cnidaria	Hydrozoa	Anthoathecata	Oceaniidae	*Turritopsis* sp.	Actiniaria sp. 4 (white)	147	6–10, 12, 13, 15–20	335–1239
Cnidaria	Hydrozoa	Anthoathecata	Oceaniidae	*Turritopsis* sp.	Actiniaria sp. 5	2	5, 7	320–731
Cnidaria	Hydrozoa	Anthoathecata	Stylasteridae	Stylasteridae		4	19	928–944
Cnidaria	Scyphozoa	Coronatae	Periphyllidae	*Periphylla* sp.		1	10	449–449
Ctenophora				Ctenophora		3	11	909–917
Echinodermata	Asteroidea			Asteroidea		302	5–20	272–1221
Echinodermata	Asteroidea			Asteroidea	Asteroidea sp. 10	7	10	409–432
Echinodermata	Asteroidea			Asteroidea	Asteroidea sp. 5	1	6	559–559
Echinodermata	Asteroidea			Asteroidea	Asteroidea sp. 8	1	9	1159–1159
Echinodermata	Asteroidea	Brisingida		Brisingida		265	7–10, 12, 16, 18–20	443–1139
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Stylasterias forreri*		4	5, 10	277–410
Echinodermata	Asteroidea	Forcipulatida	Pedicellasteridae	*Ampheraster* sp.		3	6	558–608
Echinodermata	Asteroidea	Notomyotida	Benthopectinidae	Benthopectinidae	*Nearchaster* sp. or *Cheiraster* sp.	38	6, 10, 11	408–912
Echinodermata	Asteroidea	Paxillosida		Paxillosida		1	5	294–294

Phylum	**Class**	**Order**	**Family**	**Scientific Name**	**Morphotype or Notes**	**N**	**Dive numbers**	**Depths (m)**
Echinodermata	Asteroidea	Spinulosida	Echinasteridae	*Henricia* sp.		97	5–19	310–1236
Echinodermata	Asteroidea	Valvatida	Goniasteridae	Goniasteridae		1	6	609–609
Echinodermata	Asteroidea	Valvatida	Goniasteridae	Goniasteridae	Goniasterid sp. 1	63	5–7, 11–14, 16, 17	314–1212
Echinodermata	Asteroidea	Valvatida	Goniasteridae	*Ceramaster* sp.	Ceramaster sp. 1	7	5, 7, 13	268–726
Echinodermata	Asteroidea	Valvatida	Goniasteridae	*Ceramaster* sp.	Ceramaster sp. 2	1	7	732–732
Echinodermata	Asteroidea	Valvatida	Goniasteridae	*Hippasteria* sp.		5	7, 8, 13, 19	335–958
Echinodermata	Asteroidea	Valvatida	Poraniidae	*Poraniopsis* sp.		1	13	334–334
Echinodermata	Asteroidea	Valvatida	Solasteridae	*Crossaster* sp.		3	10	406–427
Echinodermata	Asteroidea	Valvatida	Solasteridae	*Solaster* sp.		46	7, 9, 13, 16, 17, 20	333–1123
Echinodermata	Asteroidea	Valvatida	Solasteridae	*Solaster* sp.	Solaster sp. 1	3	7, 13	334–728
Echinodermata	Asteroidea	Valvatida	Solasteridae	*Solaster* sp.	Solaster sp. 2	20	7, 9, 16, 17	592–1094
Echinodermata	Asteroidea	Velatida	Pterasteridae	*Pteraster* sp.		6	9, 15, 16, 18	636–1140
Echinodermata	Asteroidea	Velatida	Pterasteridae	*Pteraster* sp.	*Pteraster cf. militaris*	3	6, 10, 18	417–665
Echinodermata	Asteroidea	Velatida	Pterasteridae	*Pteraster* sp.	*Pteraster* sp. or *Poraniopsis* sp.	1	13	341–341
Echinodermata	Asteroidea	Velatida	Pterasteridae	*Pteraster* sp.	Pteraster sp. 2	1	20	1094–1094
Echinodermata	Crinoidea			Crinoidea		29	6, 9, 20	581–1172
Echinodermata	Crinoidea			Crinoidea	Black crinoid	14	19, 20	871–1094
Echinodermata	Crinoidea	Comatulida	Antedonidae	*Florometra serratissima*		288	6, 7, 9, 11, 12, 16, 20	571–1239
Echinodermata	Echinoidea	Camarodonta	Strongylocentrotidae	*Strongylocentrotus fragilis*		30	5, 6, 10	275–570
Echinodermata	Holothuroidea			Holothuroidea		23	5, 9–11, 14, 16, 19, 20	275–1226
Echinodermata	Holothuroidea			Holothuroidea	Holothuroidea sp. 1	5	9	1050–1060
Echinodermata	Holothuroidea			Holothuroidea	Holothuroidea sp. 2	5	11, 14	697–922
Echinodermata	Holothuroidea	Dendrochirotida	Cucumariidae	*Cucumaria* sp.		1	10	416–416
Echinodermata	Holothuroidea	Dendrochirotida	Psolidae	*Psolus squamatus*		592	5–9, 12, 14–20	309–1158
Echinodermata	Holothuroidea	Elasipodida	Laetmogonidae	*Pannychia moseleyi*		179	5, 6, 9, 11, 14, 16, 18, 20	310–1236
Echinodermata	Ophiuroidea			Ophiuroidea		664	6–14, 16–20	329–1233

Phylum	Class	Order	Family	Scientific Name	Morphotype or Notes	N	Dive numbers	Depths (m)
Mollusca	Cephalopoda	Octopoda	Megaleledonidae	*Graneledone* sp.		3	19	833–934
Mollusca	Gastropoda			Gastropoda	Possibly *Fusitriton oregonensis*	328	5, 6, 8–10, 13, 16–19	264–1220
Mollusca	Gastropoda	Nudibranchia		Nudibranchia		1	19	932–932
Mollusca	Gastropoda	Nudibranchia	Tritoniidae	*Tochuina tetraquetra*		1	7	727–727
Porifera				Porifera		236	6–10, 12, 13, 15–20	329–1237
Porifera				Porifera	Demospongiae sp. 2	7	9	1058–1159
Porifera	Demospongiae			Demospongiae		144	7, 8, 18	726–963
Porifera	Demospongiae			Demospongiae	Demospongiae sp. 1	178	17–20	636–1094
Porifera	Demospongiae			Demospongiae	Possibly Homoscleromorpha	563	17–19	591–944
Porifera	Demospongiae	Poecilosclerida	Esperiopsidae	*Esperiopsis* sp.		40	7, 8, 10, 12, 13, 18	331–938
Porifera	Demospongiae	Tetractinellida	Geodiidae	*Penares cortius*		10	8	865–952
Porifera	Demospongiae	Tetractinellida	Vulcanellidae	*Poecillastra* sp.		96	8, 17–19	591–919
Porifera	Hexactinellida			Hexactinellida		307	5, 7–13, 15–20	324–1212
Porifera	Hexactinellida			Hexactinellida	Possibly Lyssacinosida	68	16, 19	901–1228
Porifera	Hexactinellida	Hexactinosida	Aphrocallistidae	*Heterochone calyx*		3	8, 13	329–858
Porifera	Hexactinellida	Hexactinosida	Euretidae	*Chonelasma* sp.		14	7, 17, 18	602–773
Porifera	Hexactinellida	Hexactinosida	Euretidae	*Pinulasma* sp.	Possibly *Pinulasma fistulosom*	211	8, 18, 19	634–957
Porifera	Hexactinellida	Hexactinosida	Farreidae	Farreidae		185	7, 8, 12, 18, 19	634–966
Porifera	Hexactinellida	Lyssacinosida		Lyssacinosida		1	19	927–927
Porifera	Hexactinellida	Lyssacinosida	Rossellidae	Rossellidae		147	7–10, 12, 13, 16–19	328–1233
Bryozoa or Cnidaria				Bryozoan/Hydroid	Possibly *Crisia* sp.	18	7–9, 12, 17, 18	649–1102
Bryozoa or Cnidaria				Bryozoan/Hydroid	Possibly *Leieschara* sp.	1	8	966–966
Bryozoa or Cnidaria				Bryozoan/Hydroid	Possibly *Plumularia* sp.	109	5, 7–11, 14–18	317–1196

Bottom dissolved oxygen concentration

The available CTD bottom oxygen values at Bowie and Hodgkins Seamounts (Figure 8) indicate that dives deeper than about 600 m fell within the core northeast Pacific oxygen minimum zone (OMZ) ([O_2] < 0.5 ml/L) (Helly and Levin 2004). An oxygen profile just south of Bowie Seamount, prepared by ESRI as part of their Ecological Marine Unit project from data in NOAA's World Ocean Atlas (http://livingatlas.arcgis.com/emu/?xmax=-15025392.779134197&xmin=-15240945.198898291&ymax=7094625.999344507&ymin=6979053.2125773765&x=-15098466.57817479&y=7006922.153556673&var=dissO2&clusterID=30&unitTop=0; https://www.nodc.noaa.gov/OC5/woa13), shows that oxygen levels increase below ~1300 m. Future analyses in SK-B MPA should take into account that benthic community structure in hypoxic habitats can be affected by differences in species-specific oxygen requirements (e.g., Chu and Tunnicliffe 2015, Chu and Gale 2017).

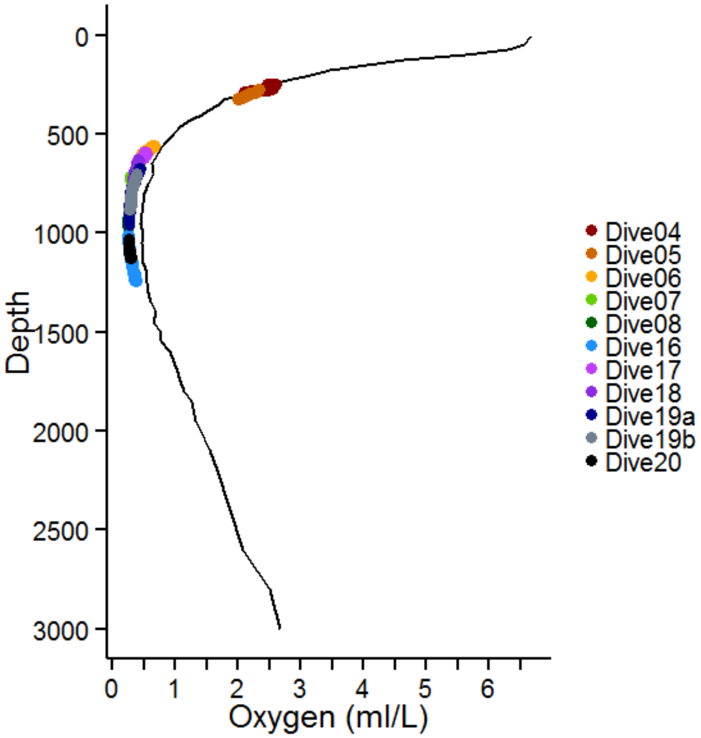

Figure 8. Dissolved oxygen depth profile for all tow-camera dives at Bowie and Hodgkins Seamounts. Solid line is the oxygen profile from a point just south of Bowie Seamount from ESRI's Ecological Marine Units project, developed using data from NOAA's World Ocean Atlas.

Acoustic Data and Water Column Sampling

Acoustic, water chemistry, and zooplankton data were collected on and around Bowie Seamount. Data processing and archive information can be found in Appendix 7. A survey grid was designed to integrate the collection of acoustic data with sampling stations for water column physical properties, chemistry, and zooplankton composition (Figure 9). The grid consisted of 4 parallel transects which were 50 nautical miles (nmi) in length and spaced 10 nmi apart. The layout of transects was designed to run perpendicular to the dominant current flow at Bowie Seamount, which runs in a southeast to northwest direction (Debby

Ianson, pers. comm.). The placement of the grid lines strategically sampled the water upstream and downstream of the seamount as well as along its ridge. The grid lines were also extended into deep water on either side of the seamount to allow for comparison of zooplankton density and composition on and off of the seamount.

Acoustic data were collected using the Simrad EK60 multi-frequency scientific echosounder of the *CCGS John P. Tully*. The system was equipped with five hull-mounted transducers operating at frequencies of 18, 38, 70, 120 and 200 kHz. Calibration of all five frequencies was performed on 4 July 2015 in Coles Bay, Saanich Inlet. The calibration was carried out following ICES recommended procedures (Demer et al. 2015) using a 38.1 mm diameter tungsten carbide sphere with a 6% cobalt binder. For this calibration, the vessel was anchored in 40 m of water and the sphere was suspended at approximately 27 m of depth, or 22 m below the face of the transducers on the hull. The sphere was positioned on-axis and moved systematically throughout the beam of each transducer. A temperature and salinity profile was recorded using a CTD at the calibration location. These parameters were used to calculate the speed of sound through water and the sound absorption coefficients. The calibration utility of the ER60 software (version 2.6.4) was used to calculate the transducers' peak gain and Sa correction values, as well as the 3 dB beam widths and their offsets. Table 6 lists the calibration parameters as well as other relevant system settings used both during calibration and the survey of Bowie Seamount.

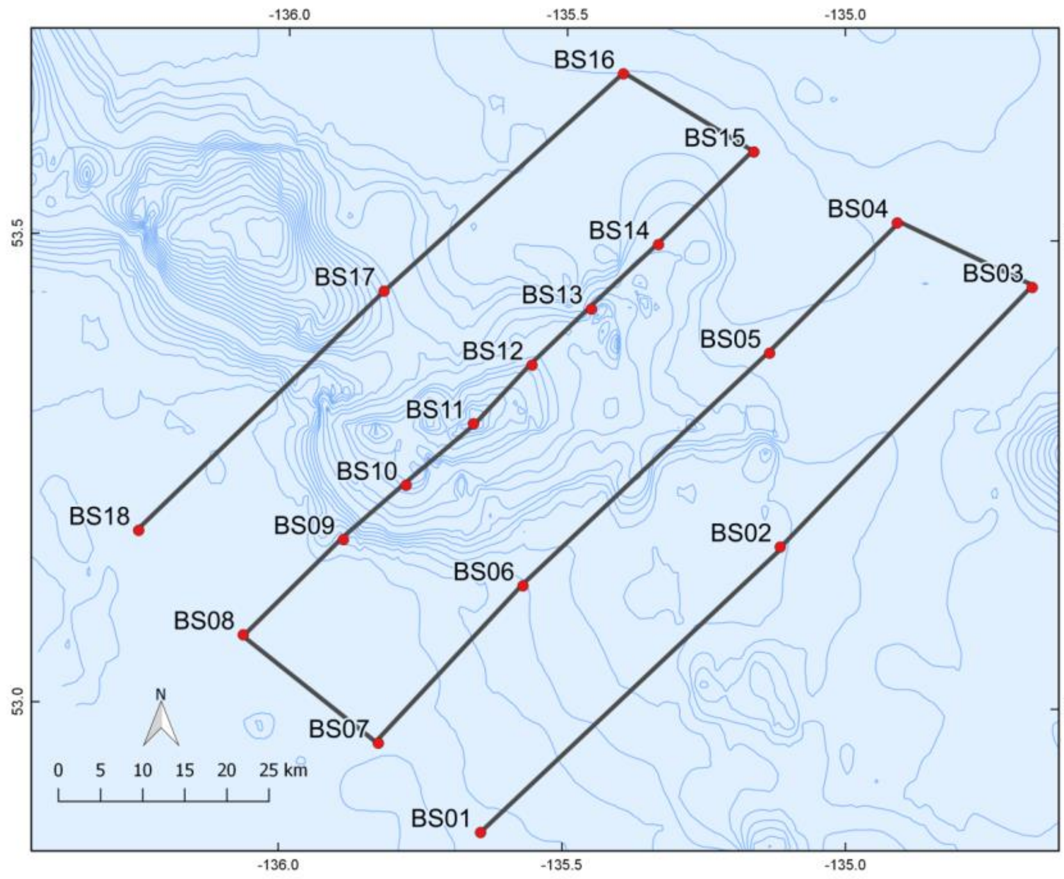

Figure 9. Bowie Seamount water column sampling stations and acoustic grid layout.

Table 6. EK60 calibration parameters and transceiver settings used during the survey.

Parameter					
Frequency (kHz)	18	38	70	120	200
SIMRAD transducer model	ES18-11	ES38B	ES70-7C	ES120-7C	ES200-7C
Transducer serial number	2064	30599	123	308	287
Transmit power (W)	2000	2000	750	250	110
Pulse duration (ms)	1.064	1.064	1.064	1.064	1.064
Transducer peak gain (dB)	22.58	18.93	26.82	27.39	26.39
S_a correction (dB)	-0.73	-0.36	-0.32	-0.37	-0.22
Bandwidth (Hz)	1570	2430	2860	3030	3090
Equivalent (two-way) beam angle (dB)	-17	-20.6	-21	-21	-20.7
Angle sensitivity (dB) alongship/athwartship	13.9	21.9	23	23	23
3 dB beamwidth (º) alongship	10.75	7.15	6.40	6.37	6.26
3 dB beamwidth (º) athwartship	10.98	6.92	6.43	6.27	6.31
Angle offset (º) alongship	-0.21	0.19	0.01	-0.02	-0.11
Angle offset (º) athwartship	0.09	-0.12	0.03	-0.02	0.10

Water column backscatter data were collected to a depth of 750 m at a rate of one ping every 1–2 seconds dependant on bottom depth. The ping rate was changed as bottom depth increased to avoid false bottom echoes from multiple returns (acoustic reverberation). Data were collected for the entire duration of the survey; however, the sounder was turned off during tow-camera operations to avoid interference with the acoustic transponders used on the camera for communication and navigation.

Acoustic data were collected both day and night and will be analyzed to assess the distribution of biota in and around the area of Bowie Seamount. Daytime coverage of the survey grid was achieved over two days when camera operations were paused to allow for comprehensive daytime acoustic coverage of the entire area. Nighttime coverage of the grid was achieved over the course of 5 nights, as sections of the grid were surveyed between sampling stations. The day and night transects will later be analyzed to compare distribution of the local seamount species at different times of the day. An example of the echogram from the 38 and 120 kHz echosounders is included in Figure 10. This echogram shows the entire length of transect 3 which ran over the top of Bowie Seamount. Visible in this echogram are the two peaks of the seamount and the biological layers that are associated with the seamount and its surrounding waters.

At each of the sampling stations, a rosette equipped with 24-10 L Niskin bottles and a 9/11 Seabird CTD was deployed. The CTD was equipped with sensors for temperature, conductivity, pressure, oxygen concentration, and fluorescence. At 12 of the 18 stations, water samples were collected down to a depth of 10m from the bottom, with the exception of BS03 which was only sampled to 250 m. Water from the rosette was collected for oxygen concentration, nutrient content, and dissolved inorganic carbon concentration. The remaining 6 stations consisted of a cast that collected data from the CTD with no water sampling. Table 7 summarizes the depths of each cast as well as types of samples taken at each station. The samples were preserved at sea to be analyzed at a later date.

Zooplankton samples were collected at all stations on the sampling grid. A bongo net with 253 µm black mesh was used to carry out a vertical haul from a depth of 250 m or 10 m off the bottom at most stations. The bongo tow resulted in two replicate samples; one was preserved in 10% buffered formalin for taxonomic analysis and the other was frozen at -80ºC for size-fractionated biomass calculations. A HydroBios midi multinet plankton sampler was utilized at three stations. This net allowed for stratified zooplankton sampling upstream and downstream of the seamount as well as on the mount itself. The multinet sampler has a mouth opening of 0.25 m^2 (0.5 m x 0.5 m) and was equipped with five nets of 250 µm mesh. Each net was triggered to open and close at specific user-defined depths. The acoustic signal (echogram) at each of the multinet stations was used to determine the depth strata sampled by each of the nets. Samples were preserved in 10% buffered formalin for taxonomic analysis. Multinet casts at stations

BS02 and BS10 were 600 m and 700 m deep, respectively, and sampled the dominant acoustic layers in the water column at each station. The multinet cast at station BS17 went to 2700 m in an effort to sample the deep water zooplankton community found around Bowie Seamount. These samples will be analyzed at a later date for taxonomic composition.

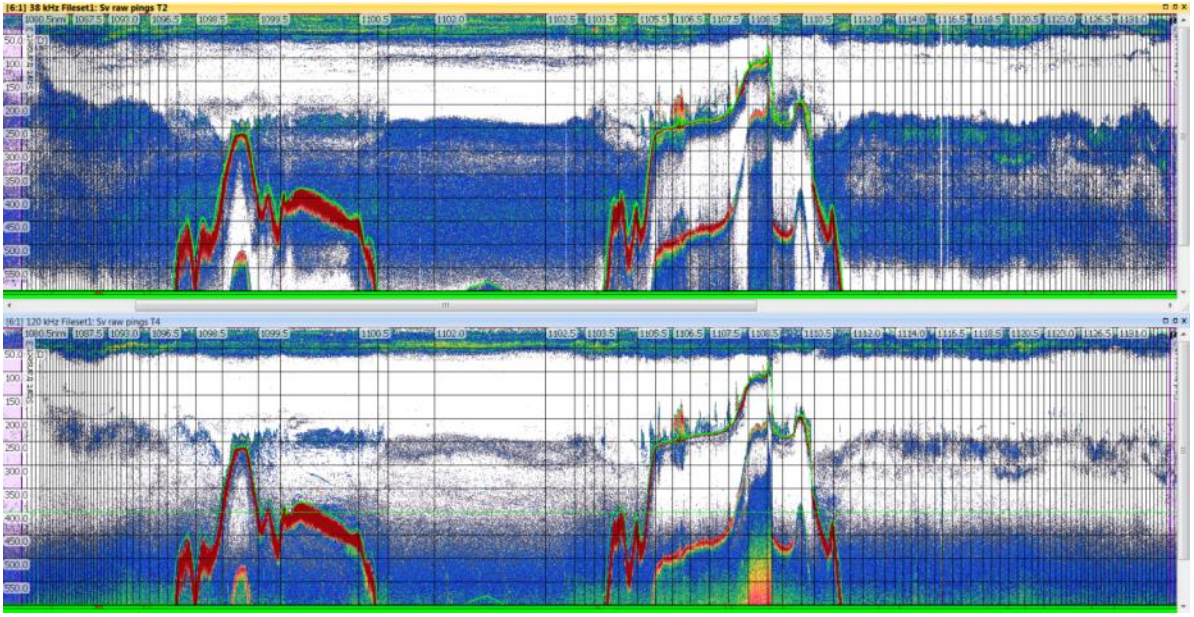

Figure 10. Echograms from the 38 and 120 kHz EK60 systems showing the water column information collected along transect 3 (waypoints BS08 to BS15). Each horizontal line represents 50 m depth (from the surface to 600 m) while each vertical line represents a distance of 0.5 nmi, and varies in spacing depending on the speed of travel. The thick red line with green highlight represents the echo return from the seamount.

Table 7. Summary of activities at sampling stations at Bowie Seamount. Water samples collected included oxygen (O), nutrients (Nut) and dissolved inorganic carbon (DIC).

Station	Bottom Depth (m)	Depth of CTD cast (m)	Water samples collected	Type of plankton net used	Depth of net cast (m)
BS01	3429	500	None	Bongo	250
BS02	2994	2984	O, Nut, DIC	Multinet	600
BS03	2883	250	O, Nut	Bongo	250
BS04	2872	500	None	Bongo	250
BS05	2853	500	None	Bongo	250
BS06	3209	250	O, Nut	Bongo	250
BS07	3476	500	None	Bongo	250
BS08	3471	3448	O, Nut, DIC	Bongo	250
BS09	3352	3342	O, Nut	Bongo	250
BS10	1050	1040	O, Nut, DIC	Bongo/Multinet	250/400
BS11	110	97	O, Nut, DIC	Bongo	100
BS12	1347	1337	O, Nut	Bongo	250
BS13	1779	1776	O, Nut, DIC	Bongo	250
BS14	2982	2957	O, Nut, DIC	Bongo	250
BS15	2940	2932	O, Nut, DIC	Bongo	250
BS16	2902	500	None	Bongo	250
BS17	2893	2883	O, Nut, DIC	Multinet	2700
BS18	3440	500	None	Bongo	250

Seabird Surveys

At-sea surveys of marine-associated birds (seabirds, seaducks, cormorants, etc.) were conducted en route to and from the Bowie Seamount area from 8–20 July 2015 aboard the *CCGS John P. Tully*. Here we provide an overview of our 2015 observations, as well as briefly discussing observations from earlier cruises, including those summarized by Canessa et al. (2003) and two other surveys (June 2001 and 2003).

At-Sea Survey Protocol

All surveys were conducted during daylight hours while the vessel was in transit (minimum speed 4 knots [7.4 km/hr]), and followed a standardized protocol similar to Tasker et al. (1984). Depending on weather conditions, observations were made from either the outside deck above the ship's bridge (Monkey's Island) or from inside the bridge. Observations were made by scanning ahead to a 90° angle from either the port or the starboard side of the vessel, depending on the glare and/or the direction of the wind (to a maximum distance of 250 m). All birds detected were identified to the lowest possible taxonomic level, enumerated, and recorded on paper data-sheets as either in flight or on the water. All birds were assigned to one of five distance bins (0–50, 51–100, 101–150, 151–200, 201–250 m) that paralleled the direction the ship was heading. Each survey (hereafter referred to as a *transect*) was ~5 min in duration. Consecutive transects were conducted throughout daylight hours, regardless of whether birds were present. At the beginning and end of each transect, the ship's position (latitude and longitude) and the time were recorded. In addition, the time and position were recorded whenever the vessel altered speed, changed course, and/or when surveying ended. At intervals of 30–60 min, we recorded a number of environmental variables including presence/absence of precipitation, maximum visibility, glare intensity and direction, cloud cover, Beaufort sea state, swell height, wind speed, and wind direction. Surveys were terminated during periods of reduced visibility (e.g., fog and/or heavy rain) and at the end of the day.

Although similar, the survey protocol in the earlier surveys (1997–2003) differed in three ways from the 2015 methods. In the earlier surveys the observations and the data recording were made by only one individual, both sides of the ship were surveyed (i.e., the total transect width equaled 500 m), and all birds seen within the survey strip were not assigned to specific distance bins.

Mapping, GIS methods, and data summarization

Using the start and end positions of the transects, transect length and mid-points were determined, and transect locations were plotted (Figure 11).

To investigate the composition and abundance of the avifauna relative to proximity to Bowie Seamount, the data were divided into two groups: (i) Northern Transects (transects with mid-points north of 51.5°N, and (ii) Southern Transects (transects mid-points south of 51.5°N). The Northern Transect mid-points were used to determine the distance to the Bowie Seamount pinnacle and water depth. The distance between the mid-point of each transect and the shortest distance to the pinnacle's 100 m isobath (contour map provided by the Canadian Hydrographic Service, Sidney, BC) was calculated to determine the distance to the Bowie Seamount pinnacle. A raster of depths collected through soundings and interpolations (Gregr 2012) was used to determine the depth for each midpoint (n = 418). Calculations were completed using ArcGIS v. 10.3 in the World Equidistant Cylindrical projection.

To determine whether there was a potential "seamount effect" on regional productivity (as per Dower and Fee 1999) the 224 northern transects were subdivided based on distance to the seamount and depth. The transects were divided into two sub-groups: those that occurred within 50 km of the pinnacle of Bowie Seamount (n = 147), and transects more than 50 km away (n = 77). As well, transects that were within 50 km of the pinnacle were further subdivided into those in waters 200 m or shallower (n = 10), and those in deeper waters (n = 137). All northern transects more than 50 km from the pinnacle were in waters deeper than 200 m. We divided the 174 southern transects into two depth groupings; transects that occurred in waters 200 m deep or less (n =79), and transects in waters greater than 200 m (n = 95). We did not subdivide the southern transects into categories based on distance to the seamount pinnacle.

To compare sightings, we used counts, average densities (derived by summing the total birds detected by species or species groups [see below] divided by the total surface area surveyed), and numbers of species for the northern and the southern transects. When we were determining the total numbers of birds and the total average densities, birds that had been identified only to a species group level (e.g., unidentified gull species) were included in the calculations. However, when deriving the number of species, birds that had been tallied at the group level were included only if there had not been a species (within that particular group) identified. For example, if an unidentified gull had been included in the tally, but there had not been a gull identified to the species level, then the unidentified gull would have been included in the count of the total number of species. On the other hand, if an unidentified gull had been observed and a gull (identified to species) had also been seen, then the unidentified gull would not have been included in the determination of the total number of species.

For the surveys conducted before 2015 (i.e., 1997–2003), we restricted our discussions to only those transects that fell within 50 km of the seamount pinnacle (n = 206). We did not divide the 1997–2003 data into water-depth categories.

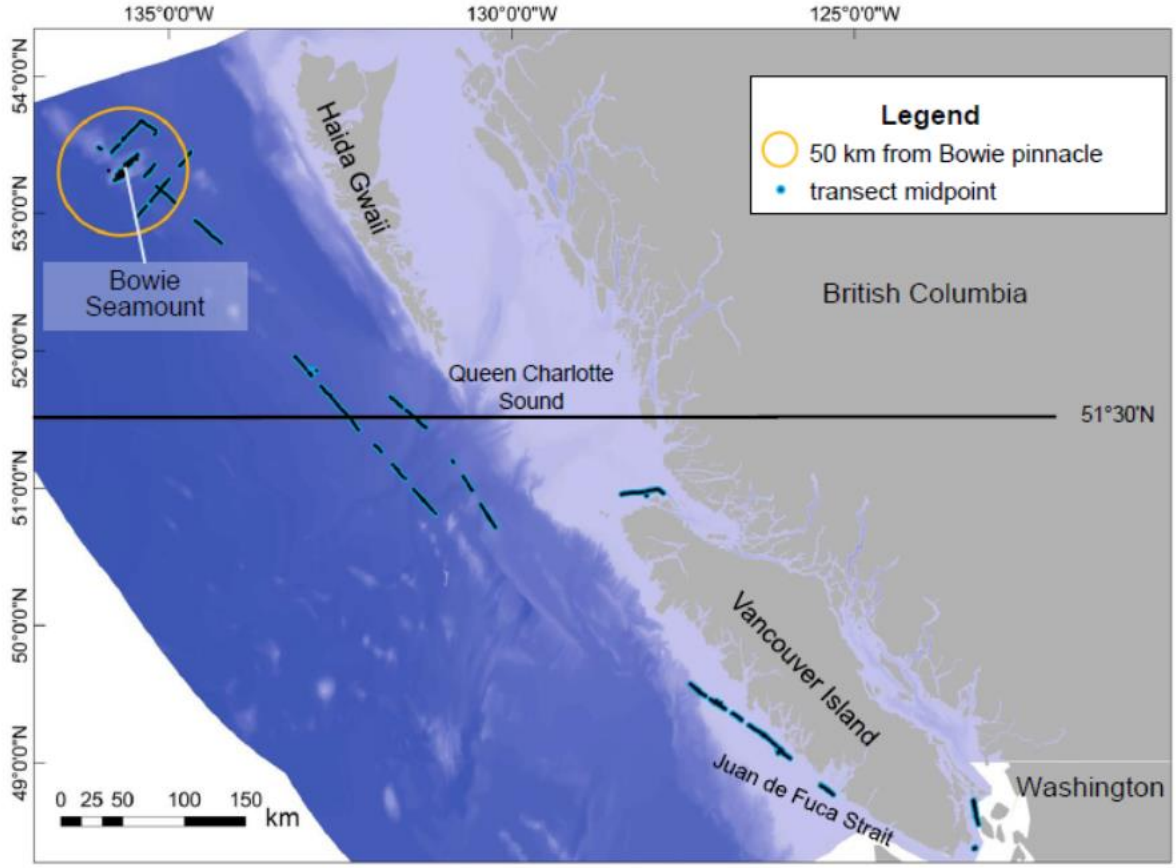

Figure 11. Location of seabird survey transect midpoints, Bowie Seamount, the 51.5°N dividing line between northern and southern transects, and the approximate location of the 50 km (radius) circle around the seamount ‘pinnacle’ (based on the 100 m isobath).

Seabird Results

A summary of the counts by species (or species groups), average densities, total densities and numbers of species observed in the northern and southern transects in 2015 is presented in Table 8. The scientific names of all species are available in Appendix 9. More species were encountered in the southern transects (19) than in the northern transects (12.). However, a large number (10) observed in the southern transects were species typically found in "nearshore" waters (i.e., generally no further than the outer edge of the continental shelf, Kenyon et al. 2009). With the exception of Fork-tailed and Leach’s Storm-Petrels, even the more typical "offshore" species (i.e., species that are usually more abundant along the outer continental shelf and over the shelf break/slope region), such as Black-footed Albatross, Pink-footed Shearwaters, and Sooty Shearwaters were also more numerous in the southern transects.

Table 8. Counts and average densities (number/km^2) of marine-associated birds observed during surveys conducted in July (2015), north and south of 51.5°N. An asterisk (*) after a species name indicates a predominantly "nearshore" species.

	North of 51.5°N		**South of 51.5°N**	
Number of transects	224		174	
Area surveyed (km^2)	75.4		63.7	
Species	**Count**	**Avg. Density**	**Count**	**Avg. Density**
White-winged Scoter*	0	–	2	0.03
Black-footed Albatross	11	0.15	34	0.53
Northern Fulmar	30	0.40	104	1.63
Pink-footed Shearwater	0	–	108	1.70
Sooty Shearwater	7	0.09	785	12.33
Unidentified shearwater sp.	1	0.01	4	0.06
Unidentified petrel (*Pterodroma* sp.)	1	0.01	0	–
Fork-tailed Storm-Petrel	203	2.69	42	0.66
Leach’s Storm-Petrel	622	8.25	150	2.36
Unidentified storm-petrel sp.	45	0.60	2	0.03
Brandt’s Cormorant*	0	–	3	0.05
Double-crested Cormorant*	0	–	1	0.02
Pelagic Cormorant*	0	–	2	0.03
Red-necked Phalarope*	0	–	12	0.19
Red Phalarope	1	0.01	0	–
Unidentified phalarope sp.	0	–	75	1.18
South Polar Skua	1	0.01	1	0.02
Parasitic Jaeger	1	0.01	0	–
California Gull*	0	–	9	0.14
Glaucous-winged Gull*	0	–	68	1.07
Sabine’s Gull	2	0.03	4	0.06
Unidentified gull sp.	0	–	6	0.09
Arctic Tern	3	0.04	0	–
Common Murre*	0	–	186	2.92
Marbled Murrelet*	0	–	2	0.03
Cassin’s Auklet	2	0.03	21	0.33
Rhinoceros Auklet*	0	–	11	0.17
Unidentified auk sp.	1	0.01	3	0.05
Total birds	**931**	**12.35**	**1635**	**25.67**
Total species	**12**		**19**	

There did not seem to be any clear patterns among the northern transects (Table 9) with respect to proximity to the seamount pinnacle and/or water depth, other than: (i) there was an apparent higher density of Fork-tailed Storm-Petrels within 50 km of the pinnacle, and over waters 200 m deep or less; (ii) an apparent higher density of Leach’s Storm-Petrels over deep waters (i.e., more than 200 m deep), more than 50 km from Bowie Seamount; and (iii) fewer species over shallow waters, within 50 km of the pinnacle. It is unknown to what extent these patterns were simply related to small sample sizes.

It is clear that the Sooty Shearwater was the dominant species present in the southern transects (Table 10), representing ~48% of all birds observed (57% of birds encountered over waters less than 200 m, ~7% of birds in deeper waters). Seven of the 17 species were only encountered in areas where the water depth was 200 m or less, versus only two species that were restricted to waters deeper than 200 m.

Table 11 compares the counts and average densities of birds observed in 2015 with those from earlier surveys. Three species (Sooty Shearwater, Northern Fulmar and Leach’s Storm-Petrel) appeared to occur at roughly the same densities in 2015 compared to earlier observations. During the earlier surveys higher numbers of Fork-tailed Storm-Petrels were encountered (at higher densities) than we encountered in 2015. Three species (South Polar Skua, Parasitic Jaeger, and Arctic Tern) were observed in 2015 only; and six species (Murphy’s Petrel, Long-tailed Jaeger, Ancient Murrelet, Cassin’s Auklet, Rhinoceros Auklet, and Horned and Tufted Puffins) were only encountered during earlier surveys.

Table 9. Counts and average densities (number/km^2) of marine-associated birds observed during surveys conducted (July 2015) north of 51.5°N, by distance from the Bowie Seamount pinnacle and by water depth categories.

	≤ 50 km from Bowie				**> 50 km from Bowie**	
	Water depth ≤ 200m		**Water depth > 200m**		**Water depth > 200m[1]**	
Number of transects	10		137		77	
Area surveyed (km^2)	3.3		45.4		26.7	
Species	**Count**	**Avg. Density**	**Count**	**Avg. Density**	**Count**	**Avg. Density**
Black-footed Albatross	3	0.90	6	0.13	2	0.08
Northern Fulmar	3	0.90	17	0.37	10	0.37
Sooty Shearwater	0	–	2	0.04	5	0.19
Unidentified shearwater sp.	0	–	1	0.02	0	–
Unidentified petrel (*Pterodroma* sp.)	0	–	1	0.02	0	–
Fork-tailed Storm-Petrel	40	12.05	115	2.53	48	1.80
Leach’s Storm-Petrel	22	6.63	323	7.11	277	10.38
Unidentified storm-petrel sp.	3	0.90	32	0.70	10	0.37
Red Phalarope	0	–	0	–	1	0.04
South Polar Skua	0	–	1	0.02	0	–
Parasitic Jaeger	0	–	1	0.02	0	–
Sabine’s Gull	0	–	2	0.04	0	–
Arctic Tern	0	–	2	0.04	1	0.04
Cassin’s Auklet	0	–	0	–	2	0.08
Unidentified auk sp.	0	–	1	0.02	0	–
Total birds	**71**	**21.39**	**504**	**11.09**	**356**	**13.35**
Total species	**4**		**11**		**8**	

[1] There were no transects > 50 km from the pinnacle in waters less than 200 m in depth.

Table 10. Counts and average densities (number/km^2) of marine-associated birds observed during surveys conducted (July 2015) south of 51.5°N, by water depth categories. An asterisk (*) after a species name indicates a predominantly "nearshore" species.

	South of 51.5°N			
	Water depth ≤ 200 m		**Water depth > 200 m**	
Number of transects	79		95	
Area surveyed (km^2)	33.3		30.4	
Species	**Count**	**Avg. Density**	**Count**	**Avg. Density**
White-winged Scoter*	2	0.06	0	–
Black-footed Albatross	20	0.60	14	0.46
Northern Fulmar	75	2.25	29	0.95
Pink-footed Shearwater	88	2.64	20	0.66
Sooty Shearwater	763	22.88	22	0.72
Unidentified shearwater sp.	4	0.12	0	
Fork-tailed Storm-Petrel	2	0.06	40	1.32
Leach’s Storm-Petrel	0	–	150	4.93
Unidentified storm-petrel sp.	0	–	2	0.07
Brandt’s cormorant*	3	0.09	0	–
Double-crested Cormorant*	1	0.03	0	–
Pelagic Cormorant*	2	0.06	0	–
Red-necked Phalarope*	10	0.30	2	0.07
Unidentified phalarope sp.	74	2.22	1	0.03
South Polar Skua	0	–	1	0.03
California Gull*	9	0.27	0	–
Glaucous-winged Gull*	63	1.89	5	0.16
Sabine’s Gull	2	0.06	2	0.07
Unidentified gull sp.	6	0.18	0	–
Common Murre*	183	5.49	3	0.10
Marbled Murrelet*	2	0.06	0	–
Cassin’s Auklet	9	0.27	12	0.39
Rhinoceros Auklet*	11	0.33	0	–
Unidentified auk sp.	3	0.09	0	–
Total birds	**1332**	**39.95**	**303**	**9.97**
Total species	**17**		**12**	

Table 11. Comparison of counts and average densities (number/km^2) of marine-associated birds observed within 50 km of the seamount pinnacle conducted in 2015 and during earlier surveys (June 1997, 1998, 2001, 2003; August 2000). An asterisk (*) after a species name indicates a predominantly 'nearshore' species.

	July 2015 ≤ 50km from Bowie		**1997–2003 ≤ 50km from Bowie**	
Number of transects	147		206	
Area surveyed (km^2)	48.7		144.6	
Species	**Count**	**Avg. Density**	**Count**	**Avg. Density**
Black-footed Albatross	9	0.18	8	0.06
Northern Fulmar	20	0.41	51	0.35
Sooty Shearwater	2	0.04	6	0.04
Unidentified shearwater sp.	1	0.02	0	–
Murphy's Petrel	0	–	2	0.01
Unidentified petrel (*Pterodroma* sp.)	1	0.02	0	–
Fork-tailed Storm-Petrel	155	3.18	1001	6.92
Leach's Storm-Petrel	345	7.08	925	6.39
Unidentified storm-petrel sp.	35	0.72	0	–
South Polar Skua	1	0.02	0	–
Parasitic Jaeger	1	0.02	0	–
Long-tailed Jaeger	0	–	1	0.01
Sabine's Gull	2	0.04	0	–
Unidentified gull sp.	0	–	1	0.01
Arctic Tern	2	0.04	0	–
Ancient Murrelet*	0	–	19	0.13
Cassin's Auklet	0	–	21	0.15
Rhinoceros Auklet	0	–	2	0.01
Tufted Puffin	0	–	12	0.08
Horned Puffin	0	–	1	0.01
Unidentified auk sp.	1	0.02	5	0.04
Total birds	**575**	**11.81**	**2055**	**14.21**
Total species	**11**		**13**	

Canessa et al. (2003) reported that seabirds have been shown to be more abundant near shallow seamounts than surrounding deeper waters and that: "*Studies around Cobb Seamount found that observed numbers of several species of seabirds were significantly higher around the seamount than elsewhere in the region (Dower and Fee 1999)*". Canessa et al. (2003) cautioned that because of the small sample size and uneven survey effort, it was not possible to determine if there had been a similar "seamount effect" on seabirds in vicinity of what is now SK-B MPA.

Focusing on our 2015 survey results, the only species that appeared to have been influenced by proximity to the seamount (i.e., showing a possible 'seamount effect') was the Fork-tailed Storm-Petrel. Both species of storm-petrels that are found in the northeast Pacific region are reported to feed on zooplankton and small fish (Watanuki 1985, Vermeer and Devito 1988). Hobson et al. (1994), using stable isotope analyses to identify trophic segregation between closely related seabird species, showed that Leach's Storm-Petrels were feeding on lower trophic-level prey (primarily invertebrates) than were Fork-tailed Storm-Petrels, which were feeding on higher trophic-level prey (especially lanternfish [Myctophidae]). Differences in diets and/or foraging methods could account for the apparent 'seamount effect' on Fork-tailed Storm-Petrels (Table 9).

The most perplexing aspect of our 2015 survey was the relative scarcity of birds, especially in the northern transects. It is possible that (to an unknown extent) the low number of birds was due to the anomalously warm waters (e.g., the "Blob", Bond et al. 2015), and/or to the strong El Nino conditions present in the northeastern Pacific Ocean in 2015. Also puzzling was the absence of auks from waters near the seamount pinnacle (Table 9, Table 11). With the exception of the sighting of a single unidentified auk, this closely-related group of birds (represented by five species in the earlier surveys), was essentially absent from the seamount area and the northern transects in 2015. While ~14% of the birds encountered in the southern transects were auks (Table 10), they represented <1% of the total number of birds observed in the northern transects in 2015 (Table 8).

Marine Mammal Surveys

Marine mammal observations were made and recorded from 8–21 July. Our objective was to observe and record cetacean sightings following DFO Cetacean Research Program protocols to obtain a measure of cetacean diversity, abundance, and distribution. While systematic line transects were not possible as part of this research cruise, the cruise provided a platform for opportunistic sightings to be collected in conjunction with other program activities. Survey effort was conducted en-route from Port Hardy to SK-B MPA, at the seamounts, and en-route to Sidney, BC along the west coast of Vancouver Island.

This report summarizes the marine mammal survey effort and the sightings obtained. Also discussed are the successes and shortcomings of conducting a cetacean survey in conjunction with other pelagic and benthic research while at the Bowie and Hodgkins Seamounts.

Methods

DFO Cetacean Research Program (CRP) protocols were employed to collect whale sightings data during daylight hours while the ship was underway. Observations were made from the outside deck above the ship's bridge (Monkey's Island) when weather permitted and from the bridge when weather conditions were less favorable.

Effort varied between one and two on-effort observers, with the two-observer methodology preferred and used for the majority of the survey. With this method the starboard observer scanned from 0° to 90° and the port observer scanned from 0° to -90°. Both on-effort observers maintained a systematic scan, and reported sightings as well as changes in weather or conditions to the data recorder. When a data recorder was not available, or when the ship was engaged in activities which conflicted with CRP protocols (e.g., ship speed < 7 knots), a one on-effort observer method was used. With this method, one observer scanned from 0° to 45°, and then from 0° to -45°. The observer maintained a systematic scan, and reported sightings and effort update information to the data recorder.

The data recorder was responsible for entering effort and sightings information into the data logging program *Logger*. This role required recording sightings conditions, and updating effort information every 30 minutes or whenever there was a change in viewing conditions. With a two-observer methodology, the observer and recorder roles rotated (port observer became starboard observer; starboard observer became data entry; and data entry became port observer) every 30 minutes during an effort update period.

Observers used 7x50 Fujinon binoculars with reticles to log sightings. Peloruses were used to measure the horizontal angle to sighted animals and were placed so that both the two-observer and one-observer teams could use them; one on the forward starboard side of the wind screen and another on the forward port side of the wind screen mounted on the Monkey's Island. Incidental sightings were also recorded. A sighting was considered incidental if it was made past 90° or -90° and had not already been reported by an on-effort observer. Because few experienced marine mammal observers were on-board, bird observers were allowed to point out sightings to the observers. However, only sightings made by bird observers which were confirmed by a marine mammal observer were recorded. A sighting was also considered incidental if observer(s) were actively surveying during conditions technically considered "off effort" (i.e., when ship speed was less than 5 knots).

As conditions and lighting permitted, observers commenced observations after breakfast (07:00) and continued to between 18:00 and 19:30, excluding 30-minute breaks for lunch and dinner. This optimized the amount of on-effort observation time.

Approximately 50% of our sightings were made with binoculars. One benefit of the binoculars was the monopods which helped steady the view and prevented arm fatigue. Two Big Eyes were installed and mounted on the Monkey’s Island; one on each the port and starboard sides. The Big Eyes were used to identify species. A Nikon D300 with a Nikkor f4.5-5.6 80-400 mm zoom lens was used for any photo ID opportunities. Photos were also taken to identify species.

The computer for logging data was stationed on the chart table located on the port side of the bridge. The GPS was placed on the port windowsill near the computer. Some data were lost when the program *Logger* crashed during surveys. A BadElf GPS Pro+ was used as back up method to record the ship’s track.

Effort

In total, 48.7 hours of on-effort scanning were conducted during the survey. Survey effort is presented in Table 12. Effort from 10–13 July and 15–18 July was limited due to slow ship speed while the *CCGS John P. Tully* was engaged in other activities.

Table 12. Summary of daily marine mammal survey effort.

Date	Total Effort (hours)
8 July	2.22
9 July	9.63
10 July	0.6
11 July	1.25
12 July	0.57
13 July	0.63
14 July	7.52
15 July	6.67
16 July	0.0
17 July	3.67
18 July	6.02
19 July	7.87
20 July	2.05
TOTAL	**48.7**

Sightings

Seven different species of cetaceans were sighted during the survey: Blue Whales (*Balaenoptera musculus*), Fin Whales (*Balaenoptera physalus*), Humpback Whales (*Megaptera novaeangliae*), Killer Whales (*Orcinus orca*), Dall's Porpoises (*Phocoenoides dalli*), Pacific White-sided Dolphins (*Lagenorhynchus obliquidens*), and Northern Right Whale Dolphins (*Lissodelphis borealis*). Official cetacean sightings also included unidentified whale, unidentified baleen whale, unidentified “like” humpback whale, large baleen whale, unidentified large baleen whale, and unidentified cetacean. On-effort cetacean sightings are shown in Table 13 and Table 14.

Other marine mammal sightings included Northern Fur Seals (*Callorhinus ursinus*), a Northern Elephant Seals (*Mirounga angustirostris*), and Steller Sea Lions (*Eumetopias jubatus*). Non-marine mammal observations included an unidentified shark and several Ocean Sunfish (*Mola mola*). Three species of cetaceans were sighted as "incidental sightings", including Dall's Porpoises, Fin Whales, and Humpback

Whales. Unidentified dolphin/porpoise, unidentified whales, and a beaked whale species (Ziphiidae) were also observed. Incidental sightings are summarized in Table 15 and Table 16.

Table 13. Number of cetacean sightings (number of individuals) by species per day while on-effort. Un. = Unidentified. Dates in bold indicate observations in the Bowie Seamount area. Multiple individuals may be sighted within an encounter.

Species	8 July	9 July	**10 July**	**11 July**	**12 July**	**13 July**	**14 July**	**15 July**	**16 July**	**17 July**	18 July	19 July	20 July	**TOTAL**
Blue Whale		1												**1**
Dall’s Porpoise		21					2	8						**31**
Fin Whale		3					1	2						**6**
Humpback Whale		2										22		**24**
Killer Whale													1	**1**
P. White-Sided Dolphin											1	1		**2**
N. Right Whale Dolphin								550						**550**
Large Baleen Whale		1												**1**
“Like” Humpback Whale		2					3	3			4			**12**
Un. Baleen Whale								2						**2**
Un. Cetacean							1							**1**
Un. Large Baleen Whale		1												**1**
Un. Whale		1					4	9		1		2		**17**

Table 14. Number of cetacean encounters by species per day while on-effort. Un. = Unidentified. Dates in bold indicate observations in the Bowie Seamount area. Multiple individuals may be sighted within an encounter.

Species	8 July	9 July	**10 July**	**11 July**	**12 July**	**13 July**	**14 July**	**15 July**	**16 July**	**17 July**	18 July	19 July	20 July	**TOTAL**
Blue Whale		1												**1**
Dall’s Porpoise		7					1	3						**11**
Fin Whale		2					1	2						**5**
Humpback Whale		2										18		**20**
Killer Whale													1	**1**
P. White-Sided Dolphin											1	1		**2**
N. Right Whale Dolphin								2						**2**
Large Baleen Whale		1												**1**
“Like” Humpback Whale		1					3	2			2			**8**
Un. Baleen Whale								2						**2**
Un. Cetacean							1							**1**
Un. Large Baleen Whale		1												**1**
Un. Whale		1					4	8		1		2		**16**

Table 15. Number of incidental cetacean sightings (number of individuals) by species per day. Un. = Unidentified. Dates in bold indicate observations in the Bowie Seamount area. Multiple individuals may be sighted within an encounter.

Species	8 July	9 July	**10 July**	**11 July**	**12 July**	**13 July**	**14 July**	**15 July**	**16 July**	**17 July**	18 July	19 July	20 July	**TOTAL**
Dall's Porpoise		6		8			5							**19**
Fin Whale			3	3										**6**
Humpback Whale				2								2		**4**
"Like" Humpback Whale						1								**1**
Un. Dolphin or Porpoise								10						**10**
Un. Whale							2	1				1		**4**
Ziphiidae							1							**1**

Table 16. Number of incidental cetacean encounters by species per day. Un. = Unidentified. Dates in bold indicate observations in the Bowie Seamount area. Multiple individuals may be sighted within an encounter.

Species	8 July	9 July	**10 July**	**11 July**	**12 July**	**13 July**	**14 July**	**15 July**	**16 July**	**17 July**	18 July	19 July	20 July	**TOTAL**
Dall's Porpoise		1		4			1							**6**
Fin Whale			2	2										**4**
Humpback Whale				1								2		**3**
"Like" Humpback Whale						1								**1**
Un. Dolphin or Porpoise								3						**3**
Un. Whale							2	1				1		**4**
Ziphiidae							1							**1**

Marine Mammal Discussion and Recommendations

The cruise provided opportunities to collect marine mammal sightings information en route to and from SK-B MPA, and within the MPA boundary when the vessel was in transit or undertaking hydro-acoustic surveys. The cetacean survey component of the SK-B MPA research cruise experienced challenges. Overall, data collection was limited by slow ship speed, which was incompatible with cetacean observer protocols.

Effort was determined primarily by vessel speed during the cruise. A speed of approximately 10 knots is required for marine mammal observers to be on effort. Due to the vessel being engaged in other activities requiring slow vessel speed, marine mammal observers were not able to follow prescribed protocols for prolonged periods of time on most days. In an attempt to maximize sighting time, a modified methodology was adopted for most of the cruise. This entailed a 30 min one-observer rotation every hour. Sightings made during these rotations were considered incidental sightings, as per observer protocols.

Having two experienced, dedicated marine mammal observers and one or two confirmed data entry assistants would have been advantageous. This would have ensured consistent utilization of the two-observer method. A fixed three-person team would also have allowed for a consistent 30-minute rotation schedule, which was not always possible. When a data entry person was confirmed for several hours at a time, the marine mammal surveying was efficient and effective.

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Appendix 1 – Science crew

Names (in alphabetical order), affiliations and roles of scientific crew aboard the *CCGS John P. Tully*, 4-21 July 2015 (CWS = Canadian Wildlife Service; DFO = Fisheries and Oceans Canada; ECCC = Environment and Climate Change Canada; HT = Highland Technologies, Inc.; IOS = Institute of Ocean Sciences; PBS = Pacific Biological Station; SFU = Simon Fraser University; UVic = University of Victoria).

Participant	**Affiliation**	**Role(s)**
Leg 1 (set up and test) and Leg 2 (Seamount)		
Emily Braithwaite	–	Volunteer (oceanography, plankton, tow-camera, species inventory)
Lily Burke	UVic	Student volunteer (tow-camera, species inventory)
Janelle Curtis	DFO (PBS)	Chief scientist
Lindsay Davidson	SFU	Volunteer (marine mammals, seabirds)
Beau Doherty	SFU	Volunteer (tow-camera, species inventory)
Katie Gale	DFO (IOS)	Survey design, species inventory, tow-camera operations
Andrew McMillan	SFU	Volunteer (tow-camera, species inventory)
Ken Morgan	ECCC/CWS (IOS)	Survey lead (seabirds)
Hamish Murray	–	Volunteer (marine mammals)
Aidan Neill	UVic	Volunteer (oceanography, plankton , tow-camera, species inventory)
Chelsea Stanley	DFO (IOS)	Survey lead (oceanography, plankton)
Wendy Szaniszlo	Contractor (DFO Marine Mammals Program)	Survey lead (marine mammals)
Kim Wallace	HT	Tow-camera assembly, testing, and operations
Jonathan Zand	HT	Tow-camera assembly, testing, and operations
Leg 1 (Set up and test) only		
Jackson Chu	UVic	Volunteer (setup, data management)
Stephane Gauthier	DFO (IOS)	Hydroacoustics
James Pegg	DFO (PBS)	Tow-camera concept design, system navigation and data management
Keith Shepherd	HT	Tow-camera design, assembly and testing
Jessica Qualley	UVic	Volunteer
Kelly Young	DFO (IOS)	Cruise setup

Appendix 2 – Conditions at sea

Wind and sea conditions during cruise PAC 2015-48. Wind speeds were averaged across hourly observations recorded in the ship's log, and swell was reported by the bridge during tow-camera dives.

Date	Wind speed in knots Mean ± SD (Range)	Swell during tow-camera dives (m)
4 July 2015	3 ± 3 (1–10)	No dives
5 July 2015	3 ± 3 (0–9)	No dives
6 July 2015	6 ± 3 (1–11)	No dives
7 July 2015	8 ± 7 (1–22)	No dives
8 July 2015	8 ± 8 (1–20)	No dives
9 July 2015	11 ± 4 (6–21)	No dives
10 July 2015	10 ± 1 (8–12)	Not recorded
11 July 2015	10 ± 2 (7–13)	Not recorded
12 July 2015	10 ± 2 (5–13)	1.5–1.8
13 July 2015	12 ± 4 (6–18)	1–2
14 July 2015	17 ± 3 (12–20)	No dives
15 July 2015	11 ± 3 (3–15)	No dives
16 July 2015	18 ± 4 (11–25)	0.5–1.5
17 July 2015	17 ± 2 (14–21)	2.7–3
18 July 2015	22 ± 4 (15–27)	No dives
19 July 2015	17 ± 9 (6–28)	No dives
20 July 2015	18 ± 4 (16–25)	No dives

Appendix 3 – BOOTS Data processing

Raw data downloaded from the CTD following the cruise was processed by G. Gatien (Institute of Ocean Sciences, DFO). The processing report is reproduced in Appendix 7.

The following steps were taken to consolidate the metadata. A text file was created with data from the CTD and tracking equipment (GPS) at 1-second intervals for each dive, with delineations indicating when transects began and ended. The following section outlines the data processing steps and considerations taken to create this file.

1. Dive log
    a. A dive log was kept during camera deployment, with time stamps recorded for key dive events (e.g., "camera power on", "video start", "descent initiated", "transect begin", "CTD not recording"). The log computer and all other computers and instruments used during the cruise were synced to the ship's clock (in UTC) to allow for all data streams to be temporally aligned. The logging computer's clock gradually developed a lag relative to the central clock over the course of the cruise (up to 10 seconds by the last dive), which was manually corrected in post processing.
2. Video alignment
    a. The three video streams (MiniZeus, 1CamAlpha-HD, 1CamAlpha-SD) recorded video files of different lengths, and only the MiniZeus had a hardcoded timestamp for all dives (the 1CamAlpha-HD had no overlay but does have embedded time and date, and the 1CamAlpha-SD only had timestamps for Dive 9 onwards). By cross-referencing the videos that did have timestamps with the dive log and matching visual landmarks in the videos, the forward facing (MiniZeus) and downward facing (1CamAlpha) video streams were aligned. Each second of dive time was recorded in a spreadsheet with the corresponding elapsed time of each video clip, to allow for cross-referencing of species records, tracking (GPS) coordinates, and CTD measurements with the videos.
3. Tracking Data
    a. *Description of positioning*. There were two positioning methods used during the survey.
        1. *USBL (ultra-short baseline) tracking*: USBL was used to determine the position of the submerged camera system during dives and is the preferred positioning method for determining the camera's location. During operations the camera's position relative to and distance from the ship is not constant; as the camera reaches the limit of its tether (wire) it pivots depending on prevailing currents and the path and heading of the ship, and will be closer or further from the ship depending on currents and the ship's speed. As such it is not possible to reconstruct the position of the camera from only the ship's location. Due to inaccurate readings for several dives (i.e., failure to get a "fix" on the camera) USBL tracking is only available for 11 of 17 dives (Dives 7–10 and 14–20).
        2. *A-frame tracking*: The position of the ship's stern and hydraulic A-frame was calculated using a standard offset from the ship's GPS (located around the centre of the ship). The A-frame position was available for all dives and was used to track the movement of the ship, and stood in for the position of the camera when USBL tracking was not available (Dives 4–6 and 11–13).
    b. *Smoothing*. The tracking strings were recorded during operations using the surveying software Hypack, which saves the files in a text format. There is some spatial error ("scatter") associated with the tracking readings, particularly for the USBL data. To correct this scatter, James Pegg (PBS) used Hypack to smooth the USBL (Dives 7–10 and 14–20) and A-frame tracklines (all dives). This software requires a depth string to process the tracklines, and

    James used the Seabird25 CTD for Dives 4–8, 17–20, and BOOTS depth gauge for Dives 9–16. The smoothed files were exported in a comma separated value (csv) format.

    c. *Standardizing interval*. The choice of depth values used in the smoothing process affected the frequency of output coordinate records. Smoothed lines using the BOOTS depth string had 1 read per approximately 0.265 seconds, while those that used the CTD output usually had 1 read per approximately 1 second. Because the record frequencies varied and generally did not fall on the whole second (e.g., 15:09:05.3434 instead of 15:09:05), the timestamps were rounded to the nearest whole second and all depth and positional records that fell within that timestamp were averaged. The final product for the tracking strings was a series of coordinates with depth values every 1 second (although some seconds were skipped due to intervals or rounding). This process was carried out for both the smoothed and raw (non-smoothed) A-frame and USBL tracks.

4. CTD data and depth
    a. Due to electrical and software problems at sea, accurate and complete CTD data (including CTD depth) was only available for Dives 4–8 and 16–20. Because the CTD's pressure sensor was only rated to 1000 m, depth readings below 1096 m (Dives 16 and 20) were not captured by the CTD. Depth values were available from an on-board pressure sensor on BOOTS tow-camera system for all dives (Dives 4–20); this sensor was considered less precise than the CTD but was necessarily used for Dives 9–15. The tow-camera CTD data output from IOSSHELL (Appendix 7) was converted to a csv file with 1 reading per second.
5. Merging
    a. The CTD data were merged with the tracking data based on the time stamp. Each record (1 per second) included ID number, dive number, date, time, depth (CTD), depth (BOOTS), coordinates (raw and smoothed USBL and A-frame), salinity, oxygen, temperature, and fluorescence.
6. Dive segments
    a. Based on the notes in the dive log, each second of video was assigned into "segments" of Descent, Transect, BottomNonTransect, Transit, or Recovery.
7. Quality control and corrections
    a. *Depth*: For Dives 16 and 20, which had good CTD data except for the portions below 1096 m, the portion under 1096 was replaced with the BOOTS depth data by matching the time stamps (Figure 12).
    b. *Salinity*: Salinity values less than 20 (interpreted to be incorrect readings at the beginning of the dive) were removed.
    c. *Oxygen*: Negative oxygen values (interpreted to be incorrect readings) were removed
    d. *Bad values*: The incorrect and incomplete Seabird25 CTD data for Dives 9–15 were completely removed. BOOTS depth data was retained for these dives.
8. Distance along transect
    a. For the smoothed USBL and A-frame tracks, the "distance along line" was calculated by converting the coordinates to Northings and Eastings (which are expressed in metres) and calculating the Euclidean distance between each set of points in m. Using these values, the transect length was calculated for each dive, using A-frame (all dives) and USBL (Dives 7–10 and 14–20).

Shapefiles including all of the above data were created for the smoothed A-frame and USBL lines.

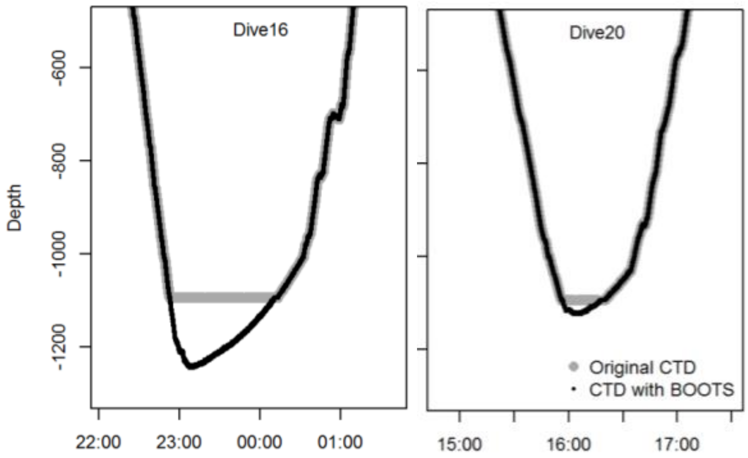


Figure 12. Depths for Dives 16 and 20. Grey lines show the original Seabird25 CTD trace, including the “floor” at ~1096 m beyond which the CTD was unable to accurately measure depth. Black lines show a composite trace, where all points deeper than 1096 m were replaced with values from the BOOTS depth sensor.

Appendix 4 – BOOTS tow-camera system technical log, procedures, and recommendations

Jonathan Zand and Kim Wallace

Tully Deck Layout

A schematic of the *Tully* deck is shown in Figure 13.

The multi-net winch was mounted on E Pad. The multinet wire was routed through a block on the A-Frame mounted heave compensation system.

The BOOTS winch was mounted on F Pad and faced 10.5 degrees inboard so it lined up with the centre of the A-frame. The BOOTS wire was routed through the BOOTS block on the A-Frame mounted heave compensation system and connected to the BOOTS tow-camera frame. When not diving, BOOTS was secured on deck between the A-Frame, except during multi-net casts when it was moved forward and port.

The Trackpoint Transceiver was mounted on a pole that pivoted near the forward port bulwarks.

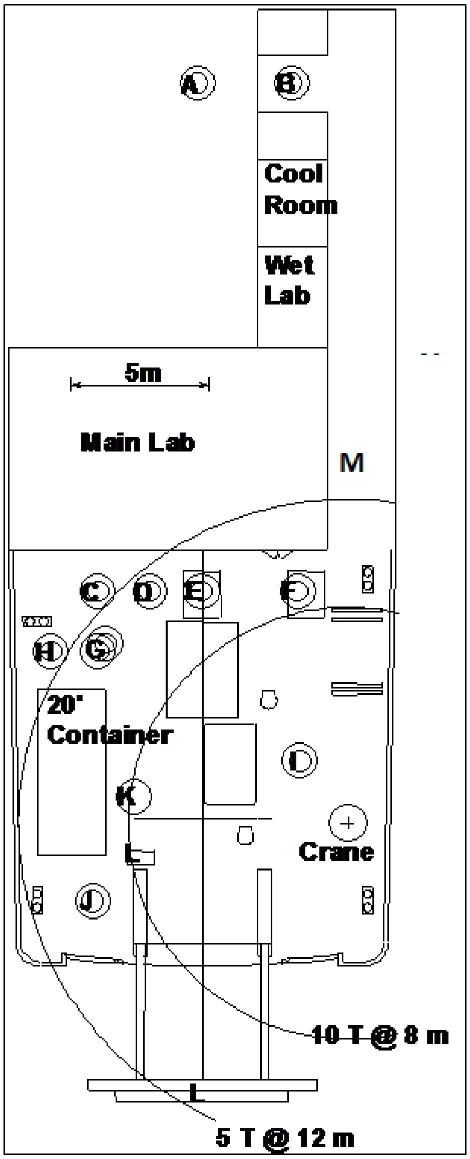


Figure 13. CCGS *John P. Tully* deck.

Technical Log

July 4, 5: System Mobilization. Load gear on *Tully*. Build Termination Box to Telemetry Canister Power Cable. Fill Pressure Compensated System with VoltEsso 35 Oil. Install CTD, P&T on BOOTS. Secure cables. Equipment Repair: 1CamAlpha camera fogging up. Open housing to install new desiccant. Terminate Umbilical and Deck Cable. Test umbilical fibre attenuation. Fibre 1: 1.7 dB; Fibre 2: 1.5.

July 6: Test Dive. Test dive in Saanich Inlet.

July 6, 7: ROS Pan & Tilt Troubleshooting. ROS not reporting Pan position. Occasionally not stopping after release of pan or tilt command. Set mechanical stops and ensured cable slack through extent of range.

Jul 6 – 8: Sonar & Altimeter Troubleshooting. Sonar comms intermittent when altimeter connected to circuit.

July 8: 2nd Test Dive. Test dive near Port Hardy

July 9: Edgetech Responder Groundfault. Build cable to connect Edgetech to BOOTS. Groundfault on system. Opened housing to investigate. Debris on o-ring caused a breech allowing some seawater into the housing. Ground connected to case by design, cannot remove ground fault condition. Dried out internals, serviced o-rings and sealed. Operate as independent unit.

July 9: Build Cable of 1Cam. Seacon was not able to build the 1CamAlpha cable in time for the July 2015 cruise, so a cable was spliced from pigtails with plain wire SOW cable.

July 10: Operational Strategy Discussed with Ship's Crew. Described operating procedure and requested feedback. Evaluated risks including winch faults and winch failure.

July 11: Edgetech Responder Charger. Documentation on Edgetech responder not accurate. Opened housing to verify charge circuit. Charged with DC power supply set to 24V, current limited to 0.2A.

July 11: ROS LED Light Adjustment. The ROS LED lights were moved aft and pitched slightly forward in an effort to improve lighting on the 1Cam video. Lighting was not improved, so the ROS LED lights were moved to their previous location and orientation.

July 11: 1CamAlpha Adjustment. The 1Cam was moved aft Moved aft 6”

July 12: Port Laser Re-Calibration. Laser spacing was within 3mm of 100mm over the first 5m, but 1 laser pointed slightly higher than the other. The vertical alignment of the lasers was adjusted between dives on July 12th. During the adjustment, the lasers were run on deck for 20 minutes. The laser housings did not feel warm.

July 13: Starboard Laser Troubleshooting. Starboard laser became dim. End of day troubleshooting established the light emitting element was not functioning correctly. There were no spare parts onboard to fix the laser.

July 14: Sync Hypack PC clock and put depth overlay on 1Cam SD video. Hypack was set up to record GPS time as a means to sync data, but the software is designed to use the computer clock for time stamps. Hypack has an application to sync the computer clock with the GPS feed but Microsoft Windows was preventing Hypack from accessing the registry to sync the clock. The security setting in ‘User Accounts and Family Safety’ was opened up to allow Hypack access to sync the clock. Once Hypack was able to sync the computer clock, the overlay string received an accurate time stamp. The 1Cam overlay serial feed was then changed from GPS (which also had an accurate time stamp), to Hypack, which not only had the accurate time and position, but also included BOOTS depth and dive number.

BOOTS Tow-Camera System Operating Procedure

The following procedure describes how the BOOTS tow-camera was deployed during DFO's July 2015 Bowie Seamount Survey aboard the *CCGS John P. Tully*.

BOOTS Techs: Kim Wallace and Jonathan Zand. Crew designations: C= Crane; F= Foredeck; H= Heave Compensation; L= Level Wind; PT= Port Tag; ST= Starboard Tag; S= Stern; W= Winch.

Pre-Launch Preparations

1.	Complete Pre-Dive Checks (see Checklist)	BOOTS Tech
2.	Deploy the Nav Pole (TrackPoint Acoustic Positioning Transceiver)	3 Crew (F, S, C) + Bosun
3.	Power down BOOTS	BOOTS Tech
4.	Assess weather forecast and sea state, consult Bridge and BOOTS Tech	Chief Sci

Deployment

5.	Launch BOOTS	3 Crew (W, PT, ST) + Bosun
6.	Commence Power Up once BOOTS is underwater	BOOTS Tech
7.	Stop Winch at 20m Payout	2 Crew + Bosun
8.	Engage Heave Compensator	2 Crew (W, L, H)
9.	Confirm all BOOTS Systems Functional; check ground fault analog values	BOOTS Tech
10.	Winch Payout to 20m Above Seafloor at 0.3m/s Past 100m, Payout can Increase to 0.4m/s if conditions allow Past 100m, Payout can Increase to 0.5m/s if swell height is < 0.5m	3 Crew (W, L, H)
11.	Approach Seafloor in 1m to 10m Increments Monitor Video, Sonar, and Altimeter to gauge altitude	Chief Sci + 2 Crew
12.	Check BOOTS Compensator Pressure Gauge	BOOTS Tech
13.	Adjust Pan & Tilt to set Zeus Camera Angle	Chief Sci + BOOTS Tech

Transect

14.	Start Transect at 0.2kt Transect Speed can increase to 0.4kt if conditions allow	Chief Sci + Bridge
15.	Direct Winch to maintain Altitude Use 0.5m or 1m increments Use Video, Lasers, Altimeter, and Sonar to monitor altitude	Chief Sci + 2 Crew (W, H)
16.	Ship Continues past the end of the Transect	Bridge

Recovery

17.	Heave to 10m Altitude and Record BOOTS Compensator Pressure	BOOTS Tech
18.	Adjust Ship Heading for Recovery	Bridge
19.	Heave to 20m Depth at 0.4m/s to 0.5m/s	3 Crew (W, L, H)
20.	Disengage Heave Compensator	Crew
21.	Record BOOTS Compensator Pressure	BOOTS Tech
22.	Power down BOOTS	BOOTS Tech
23.	Prepare 2 Tagline Hooks on Poles	Crew
24.	Ship makes way at 0.2kt water speed	Bridge
25.	Heave to 5m Depth (sight)	3 Crew + Bosun
26.	Bridge assesses Swell and provides Permission to recover Boots	Bridge
27.	Heave to Surface and Attach Taglines	3 Crew + Bosun
28.	Heave BOOTS onto Deck and Secure	3 Crew + Bosun

Post Launch

29. Recover the Nav Pole	3 Crew + Bosun
30. If Umbilical is to be Slackened for other A-Frame Operations:	1 Crew + Bosun
a. Strain Relief the Umbilical so it does not Kink	
b. Secure A-Frame Block from Swinging	
31. Perform Post-Dive Checks (see Checklist)	BOOTS Tech

BOOTS Pre-Dive Checks

Upcoming Dive:

Checked By:	Date & Time:

Physical Checks

Instruments and Cables are secure	
Compensator and Junction Box Valves are Open (inline)	
Termination Box and Junction Box air bleeds checked	
Oil filled cables to Junction Box and Zeus Camera are full	
Compensated System Pressure (10 - 15psi)	
Compensator is Full (2 – 3 inches)	
Quick Connect Caps are Fitted	
Vent Plug on Telemetry Housing is fitted	
All Connectors and Locking Collars are fitted on Termination Box	
All Connectors and Locking Collars are fitted on Telemetry Housing	
All Connectors and Locking Collars are fitted on Junction box	
Connectors and Locking Collars are fitted on all Instruments	
Umbilical, Termination Bolt, and Shackle are Secure and Undamaged	
Umbilical Shackle is Taped	
Ballast Plates are Fitted and Secure	
Seabird Magnetic Switch is On	
Edgetech Transponder Shorting Plug is fitted	
Zeus Camera Lens Cover Removed	
Zeus Camera Lens Clean	
1CamAlpha Camera Fitted and Cable Connected	
1CamAlpha Camera Lens Clean	

Operational Checks

Video from Zeus and 1CamAlpha Cameras	
Overlays on Zeus HD feed and 1Cam SD feeds	
Zeus Zoom, Focus, and Iris Control	
1Cam Control	
Lasers Visible and Aligned	
Pan & Tilt Operational and pointing at Gauge	
LED Lights	
Edgetech Transponder Chirps when Shorting Plug installed	
Free of Ground faults	
Depth, Compass, and Pitch / Roll	
Sonar and Altimeter	
CTD data streaming	
BOOTS Software Warnings Clear	
BOOTS PC Time Sync	

BOOTS Post-Dive Checks

Preceding Dive:

Checked By:	Date & Time:

Physical Checks

Instruments and Cables secure	
Compensation System Pressure	
Compensator Level	
Water Check on Termination/Transformer Can	
Water Check on Junction Box	
Water Check on Comp	
Oil filled cables to Junction Box and Zeus Camera full	
Umbilical Mechanical Termination Not Moved	
Umbilical Shackle Tape Intact	
Ballast Plates Secure	
Seabird CTD Magnetic Switch Off	
Zeus Camera Lens Cover Fitted	

Operational Checks

Lasers Aligned	
LED Lights	
Free of Ground faults	
Depth, Compass, and Pitch / Roll	
Transceiver on Pole Stopped	
1CamAlpha Camera removed for Video and Picture Download	
Edgetech Transponder on Charge	

Required Maintenance:

BOOTS Post-Cruise Checks

Cruise:

Checked By:	Date:

Equipment Checks

Address all issues noted on the last Post-Dive	
Rinse Subsea Equipment with Fresh Water	
Frame condition	
D-Rubber condition	
Comp and JB valves open and close	
Comp lines and Pressure Gauge condition	
Compensator condition	
Telemetry Housing condition	
Termination Box External condition	
Junction Box External condition	
Depth Gauge condition	
Sonar condition	
ROS P&T condition (Check Comp)	
Mini-Zeus Camera condition – Remove to Shipping Case	
Mini-Zeus Cable condition	
Laser condition	
Altimeter condition	
DSPL Projector Lights condition	
ROS LED Lights condition	
1CamAlpha Camera condition – Remove to Shipping Case	
1Cam Strobe condition	
Seabird CTD condition	
Pump fresh water through CTD plumbing	
Umbilical Termination condition	
Umbilical condition	
Winch condition	
Slip-ring condition	
Winch mounted Junction Boxes condition	
Deck cable condition	
Surface Transformer Box condition	
Surface Control Box condition	
BOOTS Laptop condition	

Subsea System De-mob

Zeus Camera packaged in Shipping Case	
1CamAlpha packaged in Shipping Case	
Instruments requiring Servicing packaged in Shipping Cases	
Oil Drained from Comp System	
Quick Connect Caps Fitted	
Fibre-Optic Attenuation on Fibre 1	
Fibre-Optic Attenuation on Fibre 2	
Umbilical End removed from Termination Box and protected	
Shackle Removed from BOOTS Lifting Eye	
Cables and Instruments remaining on BOOTS Secured	

Surface Equipment De-mob

Winch Drum Rotated to Access Rotating Junction box	
BOOTS end of Umbilical secured to Winch	
Deck cable removed from Stationary Junction Box on Winch	
Protect loose end of deck cable	
Deck cable removed from Surface Transformer Box	
Protect Loose End of Deck Cable	
Unplug Surface Transformer Box Input Power	
Unplug Surface Transformer Box from Surface Controller	
Disconnect Fibre Connection from Surface Transformer Box	
Covers Placed on Surface Controller	
Equipment and Boxes Stowed	
VoltEsso35 Oil and Pump Bottles Stowed	

Outstanding Maintenance:

Recommendations and Considerations for Future Operations

The following suggestions for future operational improvements are based on observations made during DFO's July 2015 Bowie Seamount Survey aboard the *CCGS John P. Tully*.

Deck operations

Winch level wind. The winch level wind did not automatically lay the cable evenly on the drum. Manual adjustment of the level wind was periodically necessary, requiring an extra crewmember to be on the deck during launch and recovery operations. During the transect, winch motion was typically small enough that level wind adjustments could be performed by the crew member also responsible for adjusting the heave compensation. On one occasion a bad wrap occurred during an up slope survey, and the wrap had to be fixed by moving the ship into deeper water and paying out cable beyond the bad wrap. The winch drum should incorporate a Lebus shell to assure proper spooling of the inside layer, which will enable proper spooling on upper layers. A winch configured with automatic level wind is critical to efficient and low risk operation of the BOOTS tow-camera system. The crew's diligence in monitoring and manually adjusting the level wind ensured damage free operation on the July 2015 cruise, but high utilization of experienced crew may not be available on future cruises.

Winch control. On the July 2015 cruise, winch commands were communicated to the winch operator by VHF radio. Compared to providing direct winch control in the lab, the radio communications increased delay in winch operations and introduced risk of miscommunication. A system with winch control at both the deck for near surface launch / recovery and the lab for below 20 m operations would reduce crew utilization and improve altitude control. If lab control is implemented, a video feed of the winch drum should be displayed in the lab to allow monitoring of the spooling. Lab control of winch operation may support evening or overnight operation. Once trouble free remote control of the winch is verified, it may be useful to develop a controller that automatically adjusts winch payout and heave based on altimeter and IMU observations. The winch operator's video feed (on deck or in lab) should incorporate altitude in the overlay. A graphical representation of altitude with target altitude error bars would be ideal.

Develop and install tag line guards. During launch, the tag lines are slipped when the tow-camera frame is clear of the transom. As the tails of the taglines pass through the frame, there is risk they may whip and damage an instrument or cable. Shields around the tag line attachment area would reduce the risk of damage from the tagline tail. These shields should be made of perforated material to minimize hydrodynamic drag.

Make the umbilical easily removable from the A-frame block. When the A-frame is being moved for operations other than BOOTS, the umbilical needs to be secured to avoid damage. Bongo net casts were performed with a block fitted on the A-frame ear, so the BOOTS block could remain fitted on the heave compensator in the centre of the A-frame. During bongo net casts, the BOOTS umbilical was slackened and strain relieved. Multi-net casts required a block fitted to the heave compensator, requiring the BOOTS block to be removed from the heave compensator. Attaching or removing the BOOTS block is a challenging operation requiring the crane to support the block weight while the attachment is made. The umbilical needs to be routed through the block during these operations, which risks damage to the umbilical. Using a snatch block would allow the umbilical to be easily removed from the block before these operations and reduce risk of umbilical damage. Being able to easily remove the umbilical from the block also reduces the risk of damaging the umbilical during other non-BOOTS A-frame operations.

Electrical considerations

Evaluate risk of powered launch and recovery. Power to the BOOTS system was secured for launch and recovery, which adversely affects service life of the BOOTS electronics and prevents monitoring of the BOOTS system during near surface operations. The electrical elements in the umbilical are shielded by two layers of contra-helical steel armour which is grounded to the deck. In the event of insulation failure (conductor to shield), all conductive surfaces are maintained at the same potential as the deck, effectively eliminating any risk to personnel. Risk to the equipment is mitigated by the medium voltage (1200V) ground fault interrupt system. ROV systems operating at these or higher voltages are typically deployed and recovered with power on.

Power cable replacement. The power cable and bulkhead connectors should be replaced with the originally planned Burton 5501-1508 connectors. As the cable was not in-house during mobilization, the cable and connectors were replaced with Seacon AWL-5 connectors. Brass adapters needed to be installed to fit the AWL-5 bulkhead connectors to the bulkheads designed for Burton 5501-1508 connectors. Switching to the Burton 5501-1508 connectors will provide an extra conductor required for the termination can water alarm and eliminate the need for the brass adapters.

Avoid case grounds on instruments to be integrated with BOOTS. Specify future instrument purchases to have power and com lines isolated from the housing by at least 10MOhm. If the Edgetech Responder is to be used on BOOTS in the future, investigate isolating the electrical ground from the housing. If the responder is continued to run autonomously on batteries, this ground fault will not affect BOOTS.

Junction box fuses. Currently each power circuit is protected by fuses in the telemetry canister, which makes them harder to replace than if they were located in the junction box. Fuses located in the junction box would be easier to replace, but would have to be pressure tolerant.

Subsea Equipment Improvements

CTD. The CTD depth sensor should be replaced with one rated for depths to 2500m (or the maximum depth planned for deployment). The CTD depth sensor on the July 2015 cruise was 1000m rated, so it saturated at 1095m. The Seabird 25 CTD requires 15VDC for external power. 15V is not currently available from BOOTS, but a DC-DC voltage converter could be installed in the telemetry can to provide this supply. During the July 2015 cruise, the CTD was supplied 12V, so the CTD used its internal battery power until its battery voltage dropped below 12V.

1Cam data download and cable. Having the capability to download still photos from the 1CamAlpha is essential. Removing the camera after each dive is time wasting, will shorten the service life of the subsea connectors, and introduces risk. A spare cable and bulkhead connector should be purchased if the 1Cam is to be removed and reinstalled daily. Changing the connector on the 1Cam cable to a right angle style will reduce cable bending stress. Seacon was not able to build the 1CamAlpha cable in time for the July 2015 cruise, so a cable was spliced from pigtails with plain wire SOW cable. Replacing the cable with one containing twisted pair or coax for the composite video signal will improve the quality of the SD realtime surface video captured from the 1Cam.

Humidity control. Condensation inside the telemetry was not a problem for this cruise; however, telemetry can purge capability would be an asset. At the very least, a desiccant should be available and placed in the can when it is closed up.

Heading measurements. An external compass may prove to be an asset. Whether or not an external compass is used, compass calibration should be performed.

Comp pressure monitoring. A transducer on the comp would save interruption of the video record to check comp pressure. Failing that, a low-res camera focused on the comp would suffice.

Impact resistance. Consider moving the pan & tilt with Mini-Zeus back a wee bit in the frame. Consider putting d-rubber along the side of the frame to provide cushioning in case of side impact. There is a significant risk of side impact with the A-frame uprights and cylinders during launch and recovery.

Galvanic corrosion mitigation. Galvanic corrosion occurs when dissimilar metals are electrically connected and submerged in seawater. Damage from galvanic corrosion usually requires months of submerged operation to become significant, so it can be managed by monitoring condition of equipment on a regular schedule. However, galvanic potential should be considered during material selection for future equipment installations on the BOOTS system. Materials highest on the galvanic potential scale are least likely to corrode, but cause the most damage to other materials of lower potential they are in contact with. The metals used on BOOTS, in order of increasing potential are as follows: zinc (anodes and frame coating), aluminum (P&T, telemetry can, junction box, termination can), steel (ballast plates, frame), stainless steel (fasteners), brass (MiniZeus cable locking collar, bulkhead adapters), titanium (MiniZeus, CTD).

Video lighting. Optimal light configuration is a work in progress that will continue to be empirically refined. Lighting configuration may also need to be adjusted to tune for seafloor composition, slope, and water turbidity. Based on observations from the July 2015 cruise, the 1CamAlpha (still image) field of view needs more light. The ROS (Remote Ocean Systems) LED lights provide even lighting, but do not illuminate the seafloor as much as the DSPL (Deep Sea Power and Light) HID projector lights. Given the observed power consumption of the system, additional ROS LED lights could be added. The DSPL lights are currently toed out to the limit of being blocked by the skids. A wider illumination area can be achieved by crossing the lights (point the light mounted on the port side to starboard). In general, lighting for the mini-Zeus (HD video) was adequate. We were unable to assess the effectiveness of the SubC Imaging strobe due to a failure of that unit on initial deployment. Use of an effective strobe or strobes may prove to be the best solution for the 1CamAlpha still image capture.

1Cam and altitude scaling. The 1Cam was mounted to face vertically down, so its field of view may be reasonably estimated from height above seafloor as measured by the altimeter. Further information on field of view and altitude could be achieved with the use of scaling lasers.

System documentation. A detailed 'general arrangement' drawing showing components and interconnections for the surface components (including the nav solution) should be generated.

Networking, data collection, and software considerations

Data distribution. For a number of reasons, not least of all data synchronization, all components of the system (including the nav solution) must be networked. A simple, rational network plan should be designed and implemented. A switch with at least 5 ports (preferably 8) is needed to connect all the surface devices.

Data time stamp. The system must have an NTP (network time protocol) server synced to GPS - with all computers to be networked and synced to the NTP server such that all records on every machine are automatically synchronized.

BOOTS position tracking. The navigation solution used for the 'proof of concept' dive series was designed for a different application and, while adequate, is more complex than necessary for the tow-cam. Other options should be explored. A means of displaying nav windows and vehicle video on the bridge should be developed. The solution must be portable, simple and easily implemented - preferably over the ship's network

Surface control organization. Add a shelf to accommodate the two surface Moxas and the Ethernet switch. Add a shelf to facilitate storage/transport of surface control laptop (with appropriate tie-downs).

Log files labeled with dive information. A user editable field in the GUI would allow dive number and dive series ID to be incorporated in a header attached to the log files.

Wrap counter. Observe whether the BOOTS system is spinning in the water column during descent / ascent. Deploying or ascending with some forward speed will mitigate spin.

Pan and tilt offsets. It would be nice to be able to specify the angular offsets of the pan and tilt in the BOOTS .ini file. During the July 2015 cruise, the P&T had a fault that prevented reporting of the pan position, and the tilt offset was -10 degrees (reported 10 degrees when the camera was horizontal).

Pan & tilt interface improvements. Consider extending the pan and tilt function (on the Mini-Zeus) to a joystick. The current capability to control the pan and tilt from the GUI should be retained.

BOOTS heave measurements from IMU. The SBG IG500E IMU in the telemetry can on BOOTS can estimate heave by double integrating its vertical acceleration. Consider reading these observations and displaying them on the BOOTS GUI.

Foolproofing. Some protection against accidental closure of java control application (ie 'are you sure') would be good.

Startup / shutdown script. A single button for start-up that turns on the relays to key instruments and also a single button to turn off lights and lasers could be implemented. This functionality would be in addition to having individual control of each relay.

Ground fault display and alerts. Currently the ground fault channels are individually selected in a drop down menu, and the BOOTS tech is required to cycle through and wait for each level to update. It would be useful to display the isolation values of the 8 ground fault channels in a table so they can be more easily monitored. The design of the ground fault board does not allow simultaneous inspection of these values but a cyclical background process could populate a table with recent values. Consider implementing a ground fault log, as ground fault history may be useful in post fault analysis. It would be nice to have some GUI indication of values that haven’t been recently updated. Perhaps the background colour of a value could change if not recently updated. This would extend beyond the ground fault table to all GUI numeric displays. In addition to the currently implemented ground fault visual alarms, an audible alarm would improve user alertness to deteriorating conditions. A suppress function (silence current alarm for 1 min?) should be included.

Scientific Sampling Opportunities

Hydrophone. The system has very low self-noise, so a hydrophone may be a useful and desirable option.

Niskin bottles. The system could be fitted with Niskin bottles to collect water samples near the seafloor that can be correlated to the video observations. Some hardware would need to be developed to enable triggering the Niskins.

Stereo cameras. One method of providing scale measurements for video surveys is to use 2 cameras observing the same objects from different angles to give depth perception that can be used for size calculation. Design and calibration of camera placement would be required to implement stereo vision. Currently BOOTS is implemented with 2 video channels (mini-Zeus and 1 Cam). Another two video channels can be added by installing another Yellobrik SDI over fibre unit in the telemetry canister.

Each HD video channel requires 3 co-ax connections between the camera and the SDI converter in the junction box, and each SD video channel requires 1 co-ax connection. The currently implemented Mini-Zeus camera bulkhead has 4 co-ax connections, so it can support 1 HD video camera and 1 SD video camera (requiring an appropriate y-cable to be built). The junction box has 3 co-ax connections, which could be used to support 1 HD video channel. Additional SD video channels could be routed through the Junction Box over twisted pair connections. Implementing support for up to 2 HD video cameras and 2 SD video cameras would be reasonably simple. Support for more than 2 HD and 2 SD video cameras would require major modifications to the system, including installing an additional bulkhead connector on the telemetry can for the additional co-ax connections.

Spare Interfaces

There are a number of spare interfaces available on the vehicle. Equipment deployed during the 2015 July dive series included the SubC camera, mini-Zeus camera, CTD, pan and tilt, depth sensor, sonar/altimeter, responder and lasers. Departure from planned allocation of interface resources included:

- Moving the sonar/altimeter from the Yellobrik interface to a Moxa channel
- Inability to use external power and trigger for the responder (due to ground fault in the device)
- Inability to make use of the strobe (unit flooded).

For the purposes of this discussion, utilization of spare interfaces will assume nominal allocation of resources as planned in the original design. The intent would be to return the vehicle to this configuration as soon as possible.

Serial communication channels. The original design provided An EIA 232 Channel for an optional external compass and an EIA 485 channel intended to support the altimeter. The optional compass was declined by the client and the altimeter combined the sonar on a 'Y' cable, again at the discretion of the client. This results in two spare communications channels available - one 232 and one 485.

Power outputs. The telemetry can incorporates two AC DC power supplies each providing 12 VDC and 24 VDC. Neither of these power supplies is 'maxed out'. Power is available for additional internal or external components. Power ports originally intended for the external compass and altimeter are available. Power is also available for the optional hydrophone (declined). The responder power port may also be used for an external device if the responder is operated on internal battery.

No spare relay contacts are available other than the unused compass and altimeter circuits. Five channels of an eight channel open collector switch module are available as spare. Open collector switches can provide the signal to control relays, but appropriately rated double throw relays are required to provide additional power circuits. 3 GPI channels (contact closure) are available, 2 'up' and 1 'down' (the second down channel is assigned to the transponder trigger).

One spare ground fault detection input is available.

Fibre channels. 3 Simplex fibre channels are available on the yellow brick multiplexer. Two of these could be assigned as a transmit-and-receive pair allowing addition of a fourth yellow brick or other full-duplex fibre interface. The remaining pass could be used as simplex channel (transmit only) from subsea.

Ethernet ports. Two of five ethernet ports are available on a 5-port ethernet switch in the telemetry can. Ethernet is brought to the surface via a dedicated fibre interface. These are standard ethernet ports and will support any common ethernet connected device.

Audio channels. The AJA component_video-to-HD_SDI converter used in the telemetry can has four microphone (hydrophone) inputs which are currently unused. These are not currently wired but could be put into service.

Lines in the junction box. The oil filled comms interface cable from the telemetry can to the junction box incorporates three spare shielded twisted pair elements plus the currently unused compass and altimeter pairs. There is also an unused coax element. The oil filled power cable from the telemetry can to the junction box incorporates one spare shielded twisted pair and one spare coax element. There are currently no spare plain wires in the oil filled power cable.

Appendix 5 – Video analysis protocol

Summary

Species relative abundance and habitat recorded every 10 seconds for the 10 seconds of video just viewed. Counts are recorded for fish and species of interest. The habitat variables recorded are: dominant substrate, dominant substrate percent cover, subdominant substrate, subdominant substrate percent cover, relief, image quality, survey mode, protocol, and field of view (cm).

This protocol is based on the "Semi-Quantitative" protocol used to analyze the video from Cobb Seamount (Curtis et al. 2015) with counts for most species except for very numerous species (squat lobsters, brittle stars) or colonial/encrusting fauna (demosponge, bryozoan) where relative abundance was used.

How to use Video Miner with this Protocol

Make a copy and rename the Video Miner 2.0 template database provided by DFO, not the template database installed with the software. The database installed with the software does not have the correct look-up tables. Make sure you have the latest version of Video Miner, ver. currently 3.0.8 (you may need to use an earlier version if you are using Win XP). Start the software then open the database and a video file.

In general with the software you work from left to right. At the start of each clip, fill in everything on the left side, especially the time; then, make sure the "Repeat Habitat Data" and "Record Every Second of Video" check boxes are both checked. Type 10 in the box beside the "play seconds". Click the "play seconds" button to watch the first 10 seconds of video. You can pause it if you want, and it should still stop after 10 seconds. At the end of 10 seconds you will record data for the video you just watched.

Next, click on each button in the Transect Data area and select a row from the table by clicking on the box on the left side of the row. Your selection will appear in green under the button. Then click on the "Define All" button which will bring up tables for every habitat button.

Field of view can be entered into Video Miner or using a separate software package, whichever is more effective in terms of efficiency and accuracy. If a separate software package is used, we will need a table with Time, Date, Dive, Cruise, Field of view (with any other relevant details, including units) so that field of view can be integrated into the database. The key challenge will be ensuring that the field of view records correspond to the appropriate section of video.

After everything else is filled out you can do the species observations. A relative abundance will be recorded for every species observed and counts of species of interest will also be recorded (list attached). You will need to use the "detailed entry" option in order to enter counts, but the "abundance entry" option should be faster for species where you are only entering abundance. Whether you want to switch back and forth between these two species entry modes or just use the "detailed entry" mode is personal preference.

The reason you do it in that order is that all the left side (time, date, etc.) and "Transect" fields are written for every record, but do not create a record on their own so you want them filled out before you create a record with the "Define All" button. And because we have the "Repeat Habitat Data" box checked you want to create a habitat record before you do species observations so the habitat data for the same period is written with the species observations.

Details

Date: [database field name = 'TransectDate'] Date is also from the video overlay, and since GMT time is used the date will sometimes change if a video spans midnight GMT.

Time: [database field name = 'Timecode'] Time is from the video overlay, in 24 hour format and should be GMT time.

Project Name: [database field name = ‘ProjectName ’] Project name should be the DFO Water Properties cruise number (e.g. PAC 2015-48).

Transect: [database field name = ‘TransectName’] The dive number (number only) should be used for transect name.

On/off bottom: [database field name = ‘OnBottom’] On bottom (1) is used when the bottom is visible and analysis is possible off bottom (0) is used when the bottom is not visible enough to distinguish at least substrate and large organisms.

Protocol: [database field name = ‘ProtocolID’] Protocol is usually the same for the whole project. There are currently three protocols in use.

lu_protocol		
ProtocolId	ProtocolName	Description
1	Qualitative (fast)	Species presence and habitat recorded at 10 sec intervals, dominant substrate, %, subdominant substrate, %, relief, disturbance, video quality, survey mode, protocol
2	BCTC Sponge Reef (Quantitative)	Every species counted with range (to nearest 5 cm), habitat recorded at every change, dominant substrate, %, subdominant substrate, %, relief, disturbance, video quality, survey mode, protocol
3	Semi-Quantitative	Species relative abundance and habitat recorded at 10sec intervals, counts for fish and species of interest, dominant substrate, %, subdominant substrate, %, relief, disturbance, video quality, survey mode, protocol, field of view (cm)

Survey Mode: [database field name = ‘SurveyModeID’] Survey mode is what the ROV is doing. Ideally the ROV is doing a transect (1) for most video being analysed, but in some cases the ROV will being doing other things. The categories and codes are in the table below.

lu_survey_mode			
SurveyMode Id	Entry	Description	Data Collecting
1	Transect	Transecting e.g. moving video survey of area. Video must be suitable for quantitative analysis.	Y
2	Investigation (moving)	In-depth exploration of an area/subject. This is non-transect mode but the survey instrument is still in motion. Good video of the bottom is being collected but the video is not suitable for quantitative analysis	Y
3	Investigation (still)	In-depth exploration of an area/subject. This is non-transect mode and the survey instrument is usually relatively stationary (e.g. examining an organism, bedform, etc.). Direct sampling.	Y
4	Sampling	Taking/removing a physical sample from the environment. Equipment is typically stationary. Direct sampling.	Y
5	Transiting	Moving between sampling sites sometimes too fast or too far off the bottom to see clearly. Not in survey mode. Non-directed sampling. Substrate is usually visible.	Y
6	Technical issue	Due to ROV issue not transecting correctly & cannot be annotated	N
7	Not viewed	Have not yet viewed this video (not priority survey mode conducted)	N
8	Zoom	Camera has zoomed in significantly, usually, but not always when the ROV has stopped.	Y

Image Quality: [database field name = ‘ImageQualityID’] Image (video) quality depends mainly on water quality and often does not change during a dive, but things like camera angle, lighting changes, distance off bottom, etc. can also change the quality of the video. The categories and codes are in the table below.

lu_image_quality		
Image QualityId	Label	ImageQualityDescription
1	Excellent	National Geographic quality, clear water, perfect lighting, good distance to bottom, camera steady or moving smoothly etc.
2	Good	Very good video, but not quite perfect.
3	Average	Water quality or lighting not good, but still able to see habitat and organisms clearly enough for ID
4	Poor	Water quality or lighting not good, difficult to see habitat and organisms clearly enough for ID
5	Very Poor	Water quality and or lighting poor very hard to identify even a big object unless it almost hits camera

Dominant Substrate: [database field name = ‘DominantSubstrate’] The dominant substrate is the most common substrate. The substrate codes in the table below will be used.

lu_substrate		
SubstrateId	SubstrateType	SubstrateDescription
0	Wood	Wood, Bark, or Wood Debris
1	Bedrock, smooth	Bedrock, smooth without crevices
2	Bedrock with crevices	Bedrock with crevices
3	Boulders	Boulders, bigger than a basketball
4	Cobble	Cobble, between 3 in and basketball size
5	Gravel	Gravel, between ¾ – 3 in
6	Pea Gravel	Pea Gravel, between ⅛ – ¾ in
7	Sand	Sand
8	Shell	Shell
9	Mud	Mud
10	Crushed Shell	Crushed Shell (new code 2006)
11	Whole Shell	Whole Shell (new code 2006)
12	Live Sponge	For use in sponge reefs
13	Dead Sponge	For use in sponge reefs

Dominant Substrate Percent Cover: [database field name = ‘DominantPercent’] Dominant substrate percent cover is estimated to be within one of five categories in the table below.

lu_percent		Cover Mid-point of range
Percent	PercentDescription	
1	< 5%	2.5
2	5–25%	15
3	26–50%	37.5
4	51–75%	62.5
5	> 75%	87.5

Subdominant Substrate: [database field name = ‘SubdominantSubstrate’] The second most common substrate. Same codes used as for dominant substrate.

Subdominant Substrate Percent Cover: [database field name = ‘SubdominantPercent’] Same codes used as for dominant substrate.

Species Observations: [database field name = ‘SpeciesID’] At the end of each ten seconds of video a species record will be created for every organism observed in the past ten seconds with a relative abundance.

Species Observations Reference Line: Species observations are made when an organism passes the reference line or comes closest to it. The reference line is a horizontal line across the field of view that passes through the 10 cm scaling lasers. If there are no lasers in the field of view the reference line should be in approximately the center of the field of view. If the camera angle is such that the center of the field of view does not give a clear view of organisms (tilted up so only water is visible in the middle) then the reference line will be in the middle of the area where the bottom and organisms are visible.

Species Count: [database field name = ‘SpeciesCount’] Since a record is created for every organism species count should be 1 in most cases. This is true even for organisms that do not necessarily exist as individuals such as sponges or zooanthids. You should not have a species count if you have an abundance since for this protocol abundance is only used in situations where a count is not practical.

Taxonomic Level and Identification Confidence: [database field name = ‘IDConfidence’] Each organism should be identified to the lowest taxonomic level at which you are confident of the identification (low = species, high = kingdom). So if you are not confident of the species, use genus. If you are not confident of the genus use family, etc. If you think you know a lower level taxonomic group, but are not confident, you can write it in the comment field.

Detailed Data specifications

Format

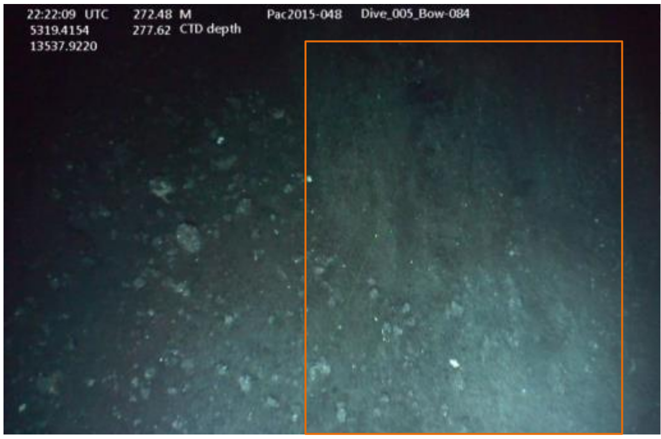
The preferred format for providing the data is a Microsoft Access database, however, a spreadsheet or comma delimited text file are also acceptable as long as the same column/field names are used.

Notes on using Video Miner to collect data for this protocol

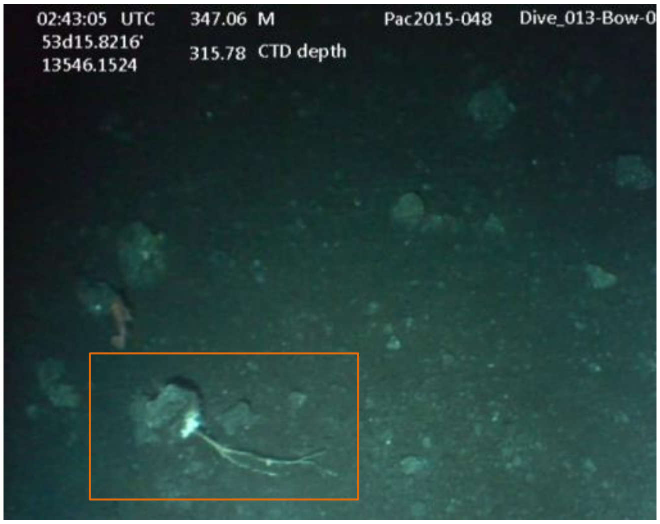
If the Video Miner software (version 2.1 or later) and your computer are set up correctly, the following information will be collected automatically:

1. video or photo file name, field name = ‘FileName’
2. video elapsed time, field name = ‘ElapsedTime”
3. reviewed date, field name = ‘ReviewedDate’ (if your computer date is correct)
4. reviewed time, field name = ‘ReviewedTime’ (if your computer time is correct)

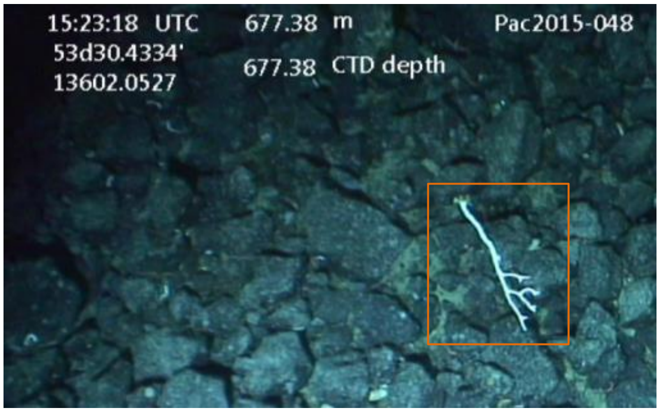
Appendix 6 – Examples of potential disturbance to the seafloor



Observation: “Dragging Signs”
Credit: DFO Science (BOOTS Tow-Camera, 2015-048)
Video still:
Pac2015-048_Dive005_PM010_222209_DragginSigns.png

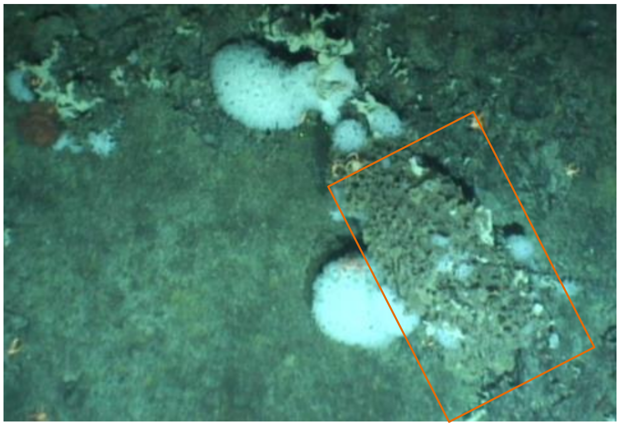


Observation: “Damaged Coral”
Credit: DFO Science (BOOTS Tow-Camera, 2015-048)
Video still:
Pac2015-048_Dive013_PM010_024305_DamagedCoral.png



Observation: “Dead Coral”
Credit: DFO Science (BOOTS Tow-Camera, 2015-048)
Video still:
Pac2015-048_Dive017_PM007_152318_DamagedCoral.png

Observation: “Dead Sponge”
Credit: DFO Science (BOOTS Tow-Camera, 2015-048)
Video still:
Pac2015-048_Dive008_PM012_192124_DeadSponge.png



Observation: “Dead Sponge”
Credit: DFO Science (BOOTS Tow-Camera, 2015-048)
Video still:
Pac2015-048_Dive008_PM013192623_DeadSponge.png

Appendix 7 – CTD data processing report

Germaine Gatien, IOS

PROCESSING NOTES

Cruise: 2015-48
Agency: MEAD
Location: North-East Pacific
Project: Seamount Ecology
Party Chief: Curtis J.
Platform: John P. Tully
Date: July 4, 2015 – July 21, 2015

Processed by: Germaine Gatien
Date of Processing: 17 February 2016 – 3 May 2016
Number of original HEX files: 1
Number of CTD files: 22
Number of Dive CTD files: 21
Number of TSG hex files: 1
Number of bottle casts: 14
Number of Dive files processed: 17
Number of TOB files: 1

INSTRUMENT SUMMARY

SeaBird Model SBE 911+ CTD (#0506) was used for this cruise. It was mounted in a rosette and attached were a Wetlabs CSTAR transmissometer (#1396DR), a SBE 43 DO sensor (#1438), a SeaPoint Fluorometer (#3640) and an altimeter (#62354).

SeaBird Model SBE25 Sealogger CTD (#0464) was mounted on a camera and attached were a SBE43 DO sensor (#0766) and a WetLabs ECO_AFL/FL fluorometer (#2215).

A thermosalinograph (Seacat 21 S/N 3363) was mounted with a WetLabs fluorometer (#WS3S-953P), a remote temperature sensor and a flow meter.

The data logging computer was #2.
The data acquisition program was Seasave.
The CTD deck unit was an SBE model 11+, serial number 0508.
There were 24 10L bottles mounted on an IOS Rosette.

SUMMARY OF QUALITY AND CONCERNS

The Daily Science Log book was in good order.

The file names were non-standard. It is helpful to save the files with the event number in them.

There are two sets of CTD files – the SBE911+ files which were mounted on a rosette frame and the SBE25 files which were mounted to the tow-camera frame. The event numbers overlap, so to avoid confusion, the SBE911+ files were named in the usual way with event numbers matching those in the Daily Science Log, ex 2015-48-0001. A leading “9” was included in the SBE25 files so that drop 4 became event 2015-48-9004.

The dissolved oxygen analyst noted concerns about the quality of the titrated oxygen samples from late in the cruise. The comparison with CTD dissolved oxygen confirmed that there was a change so that bottles from events #30-38 look different from earlier in the cruise and different from other cruises using the same CTD DO sensor. So the Oxygen:Dissolved data are reported with only 2 decimal points rather than the usual 3 to emphasize the quality concerns. Values from those casts were also flagged.

The Oxygen:Dissolved:SBE data from the SBE911+ are considered, very roughly, to be:

±0.5 mL/L from 0 to 100db
±0.2 mL/L from 100db to 500db

±0.07 mL/L from 500db to 1500db
±0.05 mL/L below 1500db

There were no salinity calibration samples. A post-cruise calibration was available but there was one cruise between this one and the factory visit so some of the drift may have occurred after this cruise.

A thermosalinograph was in use. There were no loop samples. The external thermistor worked throughout the cruise. TSG Salinity was recalibrated based on a comparison with CTD data and the history of the sensor. The fluorescence data are raw with volts as units. Based on a comparison with CTD fluorescence, it appears that TSG fluorescence in ug/L would be roughly 5 times the raw values.

An SBE25 was mounted on a dive camera. The data appear to have been averaged over 1s on acquisition, though the configuration file does not indicate that was planned. It is assumed there must have been some setting on the deck unit that caused this to happen. The CTD data have been processed, but not all the usual steps applied. No data were removed.

PROCESSING SUMMARY

NOTE: Details about the processing of the SBE25 that was mounted with the Dive Camera may be found in §25.

SBE911+ Processing

1. Seasave

This step was completed at sea; the raw data files have extension HEX.
The file names are non-standard; the station names are included in the file names but the event numbers are not, so fixing the file names requires checking each entry against the log book.
The data from the initial soak period at 10m were included in the files. These data must be removed before running DELETE.

2. Preliminary Steps

The Log Book and rosette log sheets were obtained.

Nutrients, dissolved oxygen and extracted chlorophyll data were obtained in QF spreadsheet format from the analysts.

The cruise summary sheet was completed.

The history of the pressure sensor, conductivity and DO sensors were checked.

The XMLCON files did not change through the cruise. The calibration constants were checked for all instruments and the only correction made was to the date format for the transmissometer.

The corrected file was saved as 2015-48-ctd.xmlcon.

3. Conversion of Full Files from Raw Data

All SBE911 hex files were converted using 2015-48-ctd.xmlcon to create CNV files.

The files were renamed in standard format with event numbers taken from the log book.

A few casts were examined. The stops for bottles lasted at least 30s.

All expected channels are present.

The upcast and downcast temperature and conductivity channels track in the usual way, with the upcasts generally noisier and the channel pairs further apart than during downcasts. Dissolved oxygen, fluorescence, altimetry and transmissivity profiles all look normal. The descent rate was kept high but was often very noisy.

4. BOTTLE FILE PREPARATION

The ROS files were created using file 2015-48-ctd.xmlcon. The file names were corrected to standard format.

The ROS files were converted to IOS format.

They were put through CLEAN to create BOT files.

A preliminary header check was done and no problems were found. Fluorescence did not go off-scale.

Temperature and salinity were plotted for all BOT files to check for significant outliers. Both salinity channels had some noisy patches. CTDEDIT was used to clean salinity from casts #5, 7, 17, 24 and 38.

The BOT files were bin-averaged on bottle number and the output was used to create file ADDSAMP.csv. Sample numbers were added to the file based on the rosette log records.

The addsamp.csv file was converted to CST files, which will form the framework for the bottle files.

SAM files were created using the Add Sample Number routine. Those files were bin averaged on bottle number.

Next, each of the analysis spreadsheets were examined to see what comments the analysts wanted included in the header file. These were used to create file 2015-48-bot-hdr.txt which will be updated as needed during processing.

EXTRACTD CHLOROPHYLL
The extracted chlorophyll data were provided in spreadsheet QF2015-48chl.xlsx which includes flags and comments. There were no duplicates. The spreadsheet was simplified and saved as 2015-48chl.csv.

That file was converted to individual *.CHL files.

DISSOLVED OXGYEN
Dissolved oxygen data were provided in spreadsheet QF2015-48oxy.xls which includes flags, comments and a precision study. Draw temperatures are available. The spreadsheet page with the final data was simplified and the file was then saved as 2015-48oxy.csv.

That file was converted into individual *.OXY files.

NUTRIENTS
The nutrient data were obtained in spreadsheet QF2015-48nuts.xls.

Then the file was simplified, reordered on sample numbers and saved as 2015-48-nuts.csv. The file was converted to individual NUT files.

The CHL, OXY and NUT files were merged with CST files in 3 steps. After the 3rd step the files were put through CLEAN to reduce the headers to File and Comment sections only.

The merged files are ordered on sample number, but the SAMAVG files are ordered on bottle number, so one or the other set needs to be reordered in order to merge them. The MRGCLN1 files were reordered on Bottle_Number. The output files were named MRGCLN1s. Those files were then merged with SAMAVG files choosing the Bottle_Number from the SAMAVG files.

CLEAN was run on the MRG files to add 0 flags to empty flag channels and to update header limits.

The output of the MRG files were exported to a spreadsheet and compared to the rosette log sheets to look for omissions. Nutrients were missing from cast #38 because it had been given the event #58 in the nutrient spreadsheet. The rosette log entry was hard to read. CHL was missing from events #40 and #42. The samples had been run with other cruises and got misplaced. They were found. The spreadsheet was corrected and the MRG files recreated.

5. Compare

Fluorescence
There were only 2 samples, both from the surface. There are not enough data to reach any conclusions about the performance of the fluorometer.

Event #40 – The CTD fluorescence during the bottle stop was 0.535ug/L and the extracted CHL was 0.21ug/L. The downcast CTD Fluorescence was 0.516ug/L.

Event #42 – The rosette log showed the pressure for this sample to be 90db but it was really at 2.8db. The CTD fluorescence during the bottle stop was 0.408ug/L and the extracted CHL was 0.52ug/L. The downcast CTD fluorescence was 0.39ug/L.

Dissolved Oxygen
COMPARE was run with pressure as the reference channel.

There is a lot of scatter in the comparison with the points seeming to fit roughly into 2 groups. The analyst reported a problem with replicate samples from about the halfway point in the data set. So there is likely a problem with all samples from the latter half of the cruise. No reason for the problem was found.

Because there were some deeper casts late in the cruise, the hysteresis setting could cause some scatter. A check was made to see if points below the OMZ stand out in a plot of (CTD DO – Bottle DO) vs CTD DO, but they do not.

Next, plots were made that include only data from above the OMZ. Those data show a large scatter throughout the DO range. The scatter is larger near the surface, as expected, but is still significant down to 600m. When plotted against file pair number it is clear that the scatter increases late in the cruise, which matches what the analyst noted. Those were the deepest casts, but the scatter is in the data above 800m. A plot of differences below 750m shows much less scatter, but that could be because the values are lower there and whatever is causing the problem is just less significant there.

So the problem does seem to lie with the extracted DO, meaning we cannot trust this comparison, at least late in the cruise.

When only events #3-24 are used excluding outliers based on residuals & CTD DO standard deviation >0.02, the fit is:
CTD DO Corrected = CTD DO * 1.0153 +0.0685 ($R^2 = 0.87$)

For the cruise that preceded this one (2015-18) the fit used to recalibrate this sensor was:
CTD DO Corrected = CTD DO * 1.0234 +0.0260 ($R^2 = 0.78$)

For the cruise that followed this one (2015-45) the correction applied was:
CTD DO Corrected = CTD DO * 1.0231 +0.0295 ($R^2 = 0.61$)

So the fit from the early casts are close in slope to the cruises that bracketed 2015-48, though the offset is larger.

The fit from events #30-38 with a similar approach to removing outliers was:
CTD DO Corrected = CTD DO * 1.0604 +0.0256 ($R^2 = 0.93$)

The slope is high while the offset is closer to the other 2 cruises.

The net effect is similar at the low end of the DO range, but very different at high DO.

The analyst had already noted concerns about the data from these casts, and with this comparison as further evidence, he recommended archiving Oxygen:Dissolved with only 2 decimal points to draw attention to the lower data quality.

The fits always vary somewhat, perhaps depending upon how well bottles flushed and local vertical gradients. Because there are lots of bottles with very low DO, we should be able to trust the offset, and the lower slope may reflect lower DO gradients.

A fit was done for these data that excluded DO values <2ug/L to see if the result looked like the earlier ones. The fit is quite flat from about 2ug/L to 5.5ug/L. Above that there are many outliers that have bottle values much higher than the CTD. The fit looks nothing like what we usually see. Forcing an offset by choosing the one from 2015-46 gave a reasonable slope, but the fit was very poor. The 2015-48 fit is reasonable if we exclude casts #30-38.

For more detail see document 2015-48-dox-comp1.xlsx.

Plots of Titrated DO and CTD DO against CTD salinity were examined. No further outliers were found.

6. WILDEDIT

Program WILDEDIT was run to remove spikes from the pressure, conductivity & temperature only in the full cast files (*.CNV).

Parameters used were: Pass 1 Std Dev = 2 Pass 2 Std Dev = 5 Points per block = 50

The parameter “Keep data within this distance of the mean” was set to 0 so all spikes would be removed.

7. ALIGN DO

For the cruises run before and after this one a setting of +3s was sued to align the DO signal with temperature. ALIGNCTD was run on all casts using +3s. Plots were made to check that it worked well and it did improve the alignment, but the noisy descent rates make it difficult to judge as the temperature response to shed wake corruption is so much quicker than for the DO.

8. CELLTM

The noise in the upcast makes the tests for the best parameters for this routine very difficult to interpret. Tests on previous cruises using these sensors showed the default setting of (α = 0.0245, β=9.5) did the best job and it does improve the data for both conductivity channels for these data.

CELLTM was run using (α = 0.0245, β=9.5) for both the primary and secondary conductivity.

9. DERIVE and Channel Comparisons

Program DERIVE was run on all casts to calculate primary and secondary salinity and dissolved oxygen concentration.

DERIVE was run a second time on a few deep casts to examine differences between sensor pairs.

Differences from some of the deeper casts are entered in the table below. For comparison, differences from earlier cruises and 1 later cruise using the same equipment are also shown with dark shading.

Cast #	Press	T1-T0	C1-C0	S1-S0	Descent Rate
2015-20-0111	1000	-0.0007	0	+0.0010	High, Noisy
2015-09-0018	1000	-0.0009	-0.0001	-0.0006	High, V.Noisy
2015-09-0104	1000	-0.0007	-0.0001	+0.0006	High, Moderate
2015-18-0008	230	-0.0017	-0.0010	+0.0008	High, Noisy
2015-18-0056	345	-0.0024	-0.0002	+0.0002	F.High, F.Steady
2015-18-0085	350	-0.0025	-0.0003	-0.0005	High, F.Steady
2015-48-0003	350	-0.0026	-0.0002	-0.0008	High, Noisy
	1000	-0.0014	-0.0004	-0.0026	High, Noisy
2015-48-0011	350	-0.0029	-0.0001	-0.0017	High, X.Noisy
	1000	-0.0013	-0.0003	-0.0019	High, X.Noisy
	2500	-0.0006	-0.0004	-0.0037	High, X.Noisy
2015-48-0038	350	-0.0028	-0.0003	-0.0016	High, X.Noisy
	1000	-0.0011	-0.0004	-0.0039	High, X.Noisy
	2500	-0.0008	-0.0004	-0.0043	High, X.Noisy
2015-46-0002	300	-0.0008	-0.0005	-0.0045	High, V. Steady
2015-46-0023	350	-0.0014	-0.0007	-0.0068	High, Steady
2015-46-0026	500	-0.0009	-0.0007	-0.0072	High, V.Steady
2015-46-0027	500	-0.0009 N	-0.0016	-0.0170	F.High, V.Stead
2015-46-0150	350	-0.0014	-0.0009	-0.0088	High, Noisy
	500	~ -0.004XN	-0.0010VN	-0.0087	

The differences in temperature in shallow water are high for 2015-48 but that may be due to the very heavy corruption by shed wakes caused by the extremely noisy descent rate with many complete reversals of direction. At 1000m vertical gradients are lower so that shed wake corruption is not as significant; there the results are similar to 2015-20 and 2015-09. There is little variability in conductivity differences over time. Salinity differences suggest that there might have been some drift in calibration during 2015-46, but given few deep casts and very noisy traces, this is not clear. The differences near the end of 2015-48 look similar to the differences found at the post-cruise factory check. The differences during 2015-46 look erratic and some odd shifts in salinity were noted during that cruise, so there were likely sensor problems that were not due to calibration drift. There was some suspicion about the secondary channel during 2015-46, so the primary was selected for 2015-48.

10. Conversion to IOS Header Format

The IOSSHELL routine was used to convert SEA-Bird 911+ CNV files to IOS Headers.

CLEAN was run to add event numbers and to replace pad values in the pressure channel with interpolated values based on record number.

11. Checking Headers

A cross-reference list was checked against the log book. The times in the headers are generally about 5 to 10 minutes earlier than the log times and positions differ somewhat as the ship would have moved between those two times. The header time is captured when the file is started which is sometimes just before the ship stops so positions vary somewhat as well, though it may also due to shift drift while on station.

An initial header check was run. There are clearly some spikes in at least one cast, but they are likely in the initial soak stage, so will be removed in processing.

The cruise track was plotted and added to the end of this report. The initial test cast in Saanich Inlet was not included in the plots. A blow-up of the Douglas Channel stations was added since it is hard to see this area on the full map.

Surface check was run and shows an average surface pressure for the cruise was 2.7db with a range of 1.6-4.9db. Most casts haven no pressures recorded above 1db. For one that had data from ~0.4db of the upcast with pumps running, the salinity was >31psu, so the pressure looks about right.

Plots of altimetry near the bottom were examined to see if the header entries are reasonable. Despite many spikes, the algorithm worked well except for cast #38 where it appears that the CTD got within 0.5m of the bottom rather than 11.5m. The header entry was changed for that one and the comment edited to reflect that it was not determined by the usual algorithm. The entry for cast #26 was removed as the CTD clearly never got close to the bottom.

Header entries of bottom depth and altimeter values at the bottom of the cast were exported to spreadsheets for the full files and for the bottle files. The bottom depths were checked against the log book. There were many discrepancies. An estimate of bottom depth was made by using:

Bottom depth = CTD Max Pressure * 0.99 + Altimeter Reading

Those values were compared with the header and log entries to see if it is clear which is more accurate. In some cases neither looked right. The log entry was used to change the entries for casts #5 and 7, and estimates based on the equation above were used to change the entries for cast #9 and 33. These casts are in an area where depth may vary through a cast, so using the best estimate for the time the CTD is at the bottom is a compromise.

12. Shift

Fluorescence

SHIFT was run on the SeaPoint fluorescence channel in all casts using the usual advance of +24 records. Examination of plots after this step shows that the fluorescence offset is reasonably close to the temperature offset.

Dissolved Oxygen

The Dissolved Oxygen voltage channel was aligned earlier. A few casts were checked to see if the alignment looked ok, and as usual, there is a lot of variability with the up and downcast traces sometimes closer than temperature and sometimes further apart. This is likely due to varying vertical gradients. Where there are distinct features in T and DO profiles, they line up well. Overall the choice made earlier looks appropriate, so no further alignment will be applied.

Conductivity

Tests were run on a few casts to see if what shifts to conductivity do the best job of improving salinity as judged by removing unstable features from T-S plots. There was not much difference between various choices, but overall -0.9 records looks best for the primary and +0.9 records looked best for the secondary. SHIFT was run on all casts applying those shifts. Salinity was recalculated.

13. DELETE

Before running DELETE the data acquired during the soak period had to be removed by using CLIP. Plots were made to see how many records needed to be removed; this varied from cast to cast, so this step had to be done individually for each cast.

The following DELETE parameters were used:
Surface Record Removal: Last Press Min
Maximum Surface Pressure (relative): 10.00
Surface Pressure Tolerance: 1.0 Pressure filtered over 15 points
Swells deleted. Warning message if pressure difference of 2.00
Drop rates < 0.30m/s (calculated over 11 points) will be deleted.
Drop rate applies in the range: 10db to 10db less than the maximum pressure
Sample interval = 0.042 seconds. (taken from header)

COMMENTS ON WARNINGS: There was a warning for cast #26 – the CLIP routine had been applied incorrectly, so CLIP and DELETE were rerun on that cast. Cast #5 was also found to be wrong, though there was no warning since it went a little deeper than 10m. CLIP and DELETE were rerun for that cast.

14. Other Comparisons

Previous experience with these sensors –
Conductivity, pressure and dissolved oxygen sensors were all recalibrated in late 2013 or early 2014. They were used for 1 cast during 2014-19 and all of 2014-50, 2015-01, 2015-03, 2015-17, 2015-20, 2015-09 and 2015-18 and they were used after this cruise during 2015-46.

- Both T/C sensor pairs produced salinity within 0.001 of bottles for 2015-20 and 2015-09 while from 2015-18 it appeared that both salinity channels were low by ~0.003, but the comparisons had more scatter than usual. Repairs were made to the secondary pump after 2015-17. The best comparison was from 2015-09 with many deep casts; it showed the primary to be high by an average of 0.0005 while the secondary was low by 0.0013. During 2015-46 the primary salinity was found to be low by about 0.011 and the secondary by 0.017, but there were many problems with the comparison so recalibration was postponed until a post-cruise calibration was available. See below for those results.
- The pressure sensor was found to have drifted lower by about 1.25db during 2014-50 and that offset has been used since then.
- For 2014-50 the dissolved oxygen sensor was corrected using a linear fit of slope 1.0281 since there was too little sampling of waters with low DO values to estimate an offset. For 2015-01 the fit used had a slope of 1.0187 and offset of +0.056mL/L. For 2015-03 the slope was 1.0147 and the offset +0.0647mL/L. The lower slope may be due to incomplete flushing since the sensor drift leads to CTD DO values reading low, but if the samples are from lower in the water column they will generally be reading low too. The secondary pump problem may have affected the fit as well, but it does not appear to have been a large effect. For 2015-17 the comparison had a huge scatter, so the result of 2015-01 was used. For the offshore cruises 2015-20 and 2015-09 the slope/offset values applied were 1.0235/0.0248 and 1.0246/0.0452. For 2015-18 in Juan de Fuca and Strait of Georgia it was 1.0234/0.0260.

Historic ranges – Profile plots were made with 3-standard deviation climatology ranges of T and S superimposed. All data fell within the climatology (where climatology was available).

Repeat Casts – There were no repeat casts. Nearby casts were plotted together on a T-S surface and look reasonably close.

Post-Cruise Calibration
The factory drift reports are rough and show the primary conductivity cell error leading to salinity being low by ~0.0041 which was partly offset by the primary temperature reading low by ~0.0008 deg C, for a net salinity error of something like -0.0033. The drift was also examined by reconverting a few 2015-46 files using the post-cruise calibration parameters. Those suggest the primary salinity is low by 0.0036 and primary temperature is low by 0.0013C°. That is reasonably close to the drifts found above given that the drift statement of 0.0002/month could be anywhere between 0.00015 or 0.0024 per month. For the secondary the drift was found to be smaller for both temperature and salinity with the temperature being low by ~0.0007 and salinity high by ~ 0.0013 at 500m.

15. DETAILED EDITING

The differences between the 2 salinity channels near the end of 2015-48 look similar to the differences found at the post-cruise factory check. The differences during 2015-46 look erratic and larger than the differences found post-cruise. Some odd shifts were found in both salinity channels during that cruise, so there were likely sensor problems that were not due to calibration drift. The secondary salinity looked most suspicious and upcasts were worse than downcasts, so the primary was selected for 2015-48. Flow rate variability was suspected as the source of trouble, but no cause was found for erratic flow.

For this cruise there is no evidence of the sort of shifts seen in the cruise that followed, but the descent rates are so noisy that they might not be obvious. Since the differences between salinity channels seen in these data are close to the post-cruise factory results, it looks like either channel pairs could be used.

The primary T and S channels were selected for editing as these were selected for the cruise that followed. CTDEDIT was used to remove large spikes, remove or clean smaller salinity spikes that appear to be due to instrumental problems and likely to affect the bin-averaged values and to remove records corrupted by shed wakes including some records from near the top and bottom of the casts. Some bad salinity points were also removed that are associated with decelerations of the CTD. A few casts (9, 11, 38, 40) needed heavy editing due to very noisy CTD descent rates. All files required some editing.

16. Initial Recalibration

Pressure will not be recalibrated.

The dissolved oxygen data will be recalibrated using the results of §5.

Salinity and temperature channels were recalibrated based on post-cruise calibrations.

CALIBRATE was run using file 2015-48-recal1.ccf to add 0.0036 to channel Salinity:T0:C0, to add 0.0018 to Temperature:Primary and to correct the Oxygen:Dissolved:SBE channel in the SAM and MRGCLN2 files using:

CTD DO Corrected = CTD DO * 1.0153 +0.0685

COMPARE was rerun for dissolved oxygen using the recalibrated values. The results confirm that the recalibration was applied properly.

See file 2015-48-DO-comp2.xlsx for details.

CALIBRATE was then run on the EDT files.

17. Final Calibration of DO

The initial recalibration of dissolved oxygen corrects for sensor calibration drift. Alignctd corrects for transit time errors. Those 2 steps may partly correct for response time errors, but to see if a further correction is needed, a comparison is made of downcast CTD data to bottle data from the same pressure. Small differences are always expected due to ship drift, temporal changes, incomplete flushing of Niskin bottles and noise in CTD data. This cruise is especially prone to the flushing and variability problems.

Downcast files were bin-averaged to 0.5m bins for the casts with DO bottle samples. Those files were then thinned and compared to the bottle values in the MRG files. COMPARE was run to study the differences between the downcast CTD DO data and the titrated samples from upcast bottles. The scatter in the comparison is high in the top 100m. The CTD DO is generally higher than bottles down to 800m which is what we expect if flushing is incomplete as the bottles contain water from deeper in the water column where DO is lower. Below 800m the CTD DO is close to or lower than bottles which is again expected below the Oxygen Minimum Zone. These differences are most likely due to incomplete flushing and no further calibration of CTD DO is justified.

18. Fluorescence Processing

A median filter, size 11, was applied to the fluorescence channel in the COR1 files. Plots of a few casts showed that the filter was effective. (Output:*.FIL)

19. BIN AVERAGE of CTD files

The following Bin Average values were applied to the FIL files (output AVG):

Bin channel = pressure Averaging interval = 1.000 Minimum bin value = .000

Average value will be used. Interpolated values are NOT used for empty bins.

On-screen plots were examined. No problems were found.

20. Final CTD File Steps (REMOVE and HEADEDIT)

REMOVE was run on all casts to remove the following channels:

Scan_Number, Temperature:Secondary, Salinity:T1:C1, Conductivity:Primary, Conductivity:Secondary, Oxygen:Voltage:SBE, Altimeter, Status:Pump, Descent_Rate and Flag.

A second SBE DO channel (with umol/kg units) was added.

REORDER was run to get the two DO channels together.

HEADER EDIT was used to fix formats and channel names and to add the following comments:

Data Processing Notes:

Transmissivity and Fluorescence data are nominal and unedited except that some records were removed in editing temperature and salinity.

For details on how the transmissivity calibration parameters were calculated see the document in folder "\cruise_data\documents\transmissivity".

Dissolved oxygen was calibrated using the method described in SeaBird Application Note #64-2, June 2012 revision.

The Oxygen:Dissolved:SBE data are considered, very roughly, to be:
±0.5 mL/L from 0 to 100db
±0.2 mL/L from 100db to 500db
±0.07 mL/L from 500db to 1500db
±0.05 mL/L below 1500db

For details on the processing see the report: 2015-48-proc.doc.

The Standards Check routine was run and no problems were found.

The Header Check was run and no problems were found.

The track plot looks fine.

21. Dissolved Oxygen Study

As a final check of dissolved oxygen data, % saturation was calculated and plotted. All except 1 offshore cast had surface saturations of between 103% and 104%, as expected. There was 1 offshore cast with 107%, the nearshore cast at station LG02 was ~80% and in Saanich Inlet it was ~150%. None of these values suggest any problem with the DO calibration.

22. Final Bottle Files

CALIBRATE was run on the MRGCLN2 files and then the MRGCOR1 files were put through SORT to order on increasing pressure.

REMOVE was run on all casts to remove the following channels:

Scan_Number, Temperature:Secondary, Salinity:T1:C1, Conductivity:Primary, Conductivity:Secondary, Oxygen:Voltage:SBE, Altimeter, Status:Pump, Descent_Rate and Flag.

A second SBE DO channel was added for both the CTD DO and bottle DO, with mass units and REORDER was run to get the 2 SBE DO channels together.

HEADER EDIT was run to ensure formats and units are correct, change the channel name Bottle_Number to Bottle:Firing_Sequence and the name Bottle:Position to Bottle_Number and to add a comment about quality flags and analysis methods and a few notes about the CTD data processing.

Data from the CHE files were exported to a spreadsheet and compared with rosette sheets. No problems were found. The spreadsheet was saved as 2015-48-bottles_final.xlsx.

Plots of each file were examined. No problems were found.

23. Producing final files

A cross-reference listing was produced for CTD and CHE files.

The sensor history was updated.

24. Thermosalinograph Data

There were no loop samples.

a.) Checking calibrations
The parameters in the configuration file are correct. The file was saved as 2015-48-tsg.xmlcon.

b.) Conversion of Files
There were 2 HEX files, but one was a test file.

There is some confusion about what fluorometer was mounted during this cruise. During the cruise that followed this one, 2014-46, an error was found in the configuration file; a SeaPoint fluorometer was entered where there should have been a WetLabs. So it was expected that this cruise would have the same error. However, both the log and the configuration files indicate that there was a WetLabs fluorometer. So it is hard to understand how the error crept in between the 2 cruises. Looking at the history of the instrument shows that there was a SeaPoint fluorometer on this TSG in June 2015, but the TSG was moved to the Vector where there was no fluorometer mounted. So it makes sense that a different fluorometer was mounted when the TSG was moved back to the Tully for this cruise. Just to be sure a check was made against a CTD cast for which fluorescence was ~1ug/L. If the SeaPoint configuration is used, the result is ~0.2ug/L. We do not have a calibration for the WetLabs so we only get a voltage of about 0.07, but in previous uses a comparison with CTD fluorescence suggests a scale factor of roughly 10. So 0.7ug/L would compare better with the CTD fluorescence than the 0.2ug/L found with the SeaPoint configuration. This is not conclusive evidence, but taken with the log and configuration file, it does appear that the TSG fluorometer was a WetLabs.

The HEX file was converted to a CNV file.

They were then converted to IOS HEADER format.

CLEAN was run to add End times and Longitude and Latitude minima and maxima to the headers.

ADD TIME CHANNEL was used to add Time and Date channels. (*.ATC)

The track plot and time-series plot of data both looked.

The flow rate was very steady.

c.) Checking Time Channel
The CTD files were thinned to reduce the files to a single point from the downcast at or within 0.5db of 4db. The data were exported to spreadsheet 2015-48-TSG-CTD-comp.xlsx.

The differences in latitude and longitude between the CTD casts and the TSG record when times were matched had median differences that were <0.0001°, and the maximum differences were 0.0008°, so the clock appears to have worked well and the matches made to construct the files were done correctly.

d.) Comparison of T, S and Fl from TSG and CTD data and rosette data

- T1 vs T2 The intake temperature sensor worked throughout the cruise. The heating in the loop averaged ~0.020Cº with a standard deviation of 0.03Cº.
- TSG vs CTD There were 20 casts that overlapped with TSG data.

  The intake temperature was higher than the CTD temperature by an average of 0.0135Cº and standard deviation of 0.046Cº. But the median difference was 0.007Cº. When 3 outliers are excluded the TSG is high by an average of 0.008Cº. The average of the 7 cases with the lowest standard deviation in the intake temperature also gives the TSG to be high by 0.008Cº

  The TSG salinity was found to be low by a median value of 0.095psu and standard deviation of 0.023. The results do not show any significant dependence on standard deviation in the TSG data.

  The TSG fluorescence in volts is about 20% of the CTD fluorescence in ug/L; the ratio decreases as CTD Fluorescence rises. Fluorescence did not vary greatly through this cruise.

  (See 2015-48-ctd-tsg-comp.xls.)

- TSG fluorescence versus Rosette CHL data
  There were only 2 CHL samples taken. The CHL value was about 6X the TSG reading for 1 and about 3X for the other.

- Calibration History
  The temperature and conductivity sensors were recalibrated in December 2013 and have been used for 7 previous cruises since then and for 4 that have occurred since then. The fluorometers used have varied and some of the cruises were on the Vector with no fluorometer.

  - During 2014-21 the TSG salinity was found to be lower than loop samples and CTD salinity by ~0.03 but the difference varied with flow rate which was highly variable. No recalibration was applied due to the variability in the comparisons and the fact that such a large drift in calibration on its first use seemed unlikely.

- During 2014-19 the TSG salinity was found to be low by ~0.02, and the TSG temperature was found to be higher than the CTD temperature by ~0.005Cº.
- 2014-22 results were not trusted.
- 2015-01 salinity data were recalibrated by adding 0.02. Intake temperature was found to be higher than CTD temperature by from 0.005 Cº to 0.007 Cº.
- During 2015-20 the salinity was found to be low by 0.025, the intake temperature high by ~0.008Cº.
- During 2015-09 salinity was found to be low by about 0.03 and the intake temperature was higher than the CTD temperature by ~0.004Cº to ~0.006Cºf
- During 2015-18 the TSG was on the Vector with no loops, no intake temp, and high gradients making comparisons with CTD data unreliable.
- No useful comparison could be made using 2015-46 results.
- For 2015-10 the TSG was lower than loops by 0.17 and lower than the CTD by 0.1 to 0.18. Recalibration was done by adding 0.18 to the salinity.
- For 2015-21 the intake temperature was higher than the CTD temperature by a median of 0.011Cº. The salinity was low by ~0.18 but the comparison was noisy.
- During 2014-61 the intake temperature malfunctioned. The TSG salinity was lower than the CTD by between 0.04 and 0.1 and lower than loops by 0.05. Recalibration added 0.014 to salinity.

Conclusions

1. The TSG clock worked well.
2. The TSG flow rate was steady and high.
3. The TSG fluorescence is given in volts. For a very rough estimate of fluorescence you can multiply by 5, but understand that the factor varies.
4. The history of this TSG since it was last calibrated shows a lot of variability, some of which may be explained by it being used on different ships. It is thought that bubbles in the Tully loop may explain low salinity values; evidence for this includes spikes that are always towards lower salinity values. The TSG set-up on the Tully varies from cruise to cruise, and it is possible that other factors such as weather conditions may be factors.
5. The two offshore cruises that bracket this one found very different results when comparing TSG salinity with loop samples and CTD data. The salinity comparison for this cruise falls between the two with salinity low by 0.095. While there is a lot of scatter in the fit, it is clear that the salinity is low and 0.095 looks like a good number to use. There are spikes in the salinity record that do suggest there are some bubbles. There may well be many small ones that are not obvious accounting for the overall low values.
6. The TSG temperature is close enough to the CTD temperature that recalibration is not justified given that minor mismatches in depth may account for at least some of the difference.

f.) Editing

The salinity has some obvious spikes to low values. CTDEDIT was used to reduce a few records at the beginning of the file as flow was being established. Single-point spikes in salinity were cleaned where they were not matched in the temperature trace.

g.) Recalibration

File 2015-48-tsg-recal.ccf was prepared to add 0.095 to the salinity channel and was applied to the *.EDT file.

h.) Preparing Final Files

REMOVE was used to remove the following channels from all casts: Scan_Number, Temperature:Difference, Conductivity:Primary, Position:New, Flag

HEADER EDIT was used to add a comment, change the DATA TYPE to THERMOSALINOGRAPH and add the depth of sampling to the header and to change channel names to standard names and formats.

The file was saved as a TOB file.

A Standards Check and Header Check were run and no problems were found.

The TSG sensor history was updated.

As a final check plots were made of the cruise track and it looks fine.

The cruise plot was added to the end of this report (Figure 17).

25. SBE25 Data

The SBE25 was mounted on a dive camera. In some cases there were multiple files for a single dive.

These data are not suitable for the OSD Data Archive, given highly variable descent rates and gaps, but for use of the chief scientist in conjunction with the dive camera.

The RAW file names were copied to a different folder and renamed in standard format, but with a leading 9 in the event number, ex 2015-48-9004.hex. This is to distinguish this set of casts from those taken with the SBE911+ with the rosette.

a) CONVERT

The configuration file was correct and was saved as 2015-48-dive-ctd.xmlcon.

All casts were converted using configuration file 2015-48-ctd.xmlcon.

Plots show that the channels all produced reasonable values except for the descent rate which is extremely high. Investigation could find no problem in the headers or configuration file to explain this – the sampling rate was correct. The data must have been averaged on acquisition, though it left no trail in the header. So the descent rate looks 8 times as high as it really is. Many of the usual processing steps will be inappropriate for 1s-averaged data.

b) WILDEDIT

This step was skipped since any spikes will have been removed by the averaging already applied.

c) WFILTER

The averaging on acquisition means these data do not have a lot of reversals but there are some. Also since the header indicates that the sampling rate is 8 hertz, whereas the file only contains 1 record per second, it is likely that the usual settings would have a much greater effect than usual. Applying them does remove a few spikes, but those spikes look like they are due to shed wakes and so it is better to use DELETE to remove them, rather than smooth them.

This step was skipped.

d) ALIGNCTD

Tests were run on a few casts to see what alignment made the offset between the upcast and downcast DO traces resemble that for the temperature traces. An advance of 1s produced the best results; given the header error this is assumed to be effectively 8s.

ALIGNCTD was run on all casts to advance the DO channel by 1s.

e) CELLTM

The usual setting for this step did not work well on these data and none was found that made any significant difference. The upcast and downcast traces were already in good correspondence, so this step is not needed.

f) DERIVE

Program DERIVE was run to calculate salinity and dissolved oxygen concentration (tau correction included).

g) Conversion to IOS Headers

The IOSSHELL routine was used to convert the CNV files to IOS Headers.

There are two events with more than 1 file:

- Cast 9 had 4 files but only the 1st had any useful data. There is no upcast data.
- Cast 11 had 2 files. The first has nothing useful and the 2nd has downcast data with a big gap and no upcast. So 11 was renamed 11a and 11b was renamed 11.

There were other casts with gaps: 12, 13, 14 & 15.

Spreadsheet 2015-48_merge_headers.csv was prepared to add station names, event numbers, latitude and longitude. These steps are finicky – format has to be just right.

Program MERGE:CSV FILE TO HEADERS was run to add that information to the headers of the IOS files.

The MRG files were edited to change the time interval from 0.1250 to 1.0000.

ADD TIME CHANNEL was run to add 7 hours to time to get UTC (since the original times appear to be in PDT) and to add times to every record. A few files were checked against the DIVE log records and the end times compare well with the log.

h) Checking Headers

A cross-reference listing was produced and the entries look reasonable, though no leg was available for these casts.

A track plot was produced and added to the end of this report.

HEADER CHECK was run. There are some negative pressures that clearly correspond to a time when the CTD was out of the water. The descent rate is much too high, but this is believed to be because the data were averaged on acquisition. Dividing the descent rate by 8 produces believable values and the header shows there were 8 records per second.

The surface check shows that most casts started below 10m. Of the 3 that did not, 2 have negative pressures (-0.8 and -0.5db) but also very low conductivity so that the CTD might have been out of water or pumps were not working. The upcasts are not useful in assessing the accuracy of the pressure as most do not include near-surface records and some have negative values but the data suggests the CTD was out of water. There is no evidence to enable a judgment on the accuracy.

i) DELETE

A test run of DELETE demonstrated that the record would be fragmented and need heavy editing; the upcast sections may well be of interest to the researchers as may other data that would be removed.

j) Final Steps

REMOVE was run to remove channels Conductivity:Primary, Oxygen:Voltage:SBE and Flag.

DERIVED QUANTITES was run to calculate Depth.

HEADER EDIT was run to change the format for Pressure and Depth and to add the following comments to the headers:

> *Data Processing Notes:*
> *These data were processed for the use of the researchers and are not intended*
> *to go into the IOS DATA ARCHIVE. They will be archived elsewhere.*
> *The CTD was an SBE25 mounted on a drop camera frame.*
> *There were frequent interruptions in the data acquisition.*
> *No data were removed in processing.*
> *File names have a leading 9 in the event number section to distinguish them from*
> *CTD casts that occurred at other sites and deployed an SBE911+.*
> --

A cross-reference listing was produced.

These files were then sent to Katie Gale for her use. The files are not suitable for the OSD Data Archive, given low and highly variable descent rates and many stops and gaps.

CRUISE SUMMARY

CTDs

CTD#	Make	Model	Serial#	Used with Rosette?
	SEABIRD	911+	0506	Yes
	SEABIRD	25	0464	No

Calibration Information SBE 911+ CTD

Sensor		Pre-Cruise		Post Cruise	
Name	**S/N**	**Date**	**Location**	**Date**	**Location**
Temperature	**2023**	**31Jan2013**	**Factory**		
Conductivity	**1763**	**1Jan2014**	**Factory**		
Secondary Temp.	**5013**	**27Feb2013**	**Factory**		
Secondary Cond.	**3394**	**3Jan2014**	**Factory**		
Transmissometer	**1396DR**	**5Feb2014**	**IOS**		
SBE 43 DO sensor	**1438**	**3Jan2014**	**Factory**		
SeaPoint Fluor.	**3640**	**n/a**			
Pressure Sensor	**506**	**30Dec2013**	**Factory**		
Altimeter	**62354**	**n/a**			

Calibration Information SBE25 CTD

Sensor		Pre-Cruise		Post Cruise	
Name	**S/N**	**Date**	**Location**	**Date**	**Location**
Temperature	**2968**	**23Dec2014**	**Factory**		
Conductivity	**2173**	**19Dec2014**	**Factory**		
SBE 43 DO sensor	**0766**	**23Dec2014**	**Factory**		
WetLabs Eco Fluor.	**2215**	**2July2015**	**IOS**		
Pressure Sensor	**0464**	**23Dec2014**	**Factory**		

CRUISE SUMMARY TSG

Make/Model/Serial#: SEABIRD/21/3363 **Cruise ID#:** 2015-48

Calibration Information

Sensor		Pre-Cruise		Post Cruise	
Name	**S/N**	**Date**	**Location**	**Date**	**Location**
Temperature	**3363**	**28Dec13**	**Factory**		
Conductivity	**3363**	**28Dec13**	**Factory**		
WetLabs Fluorometer	**WS3S-953P**	**?**			
Temperature:Secondary	**?**	**?**			
Flow meter	**?**	**n/a**			

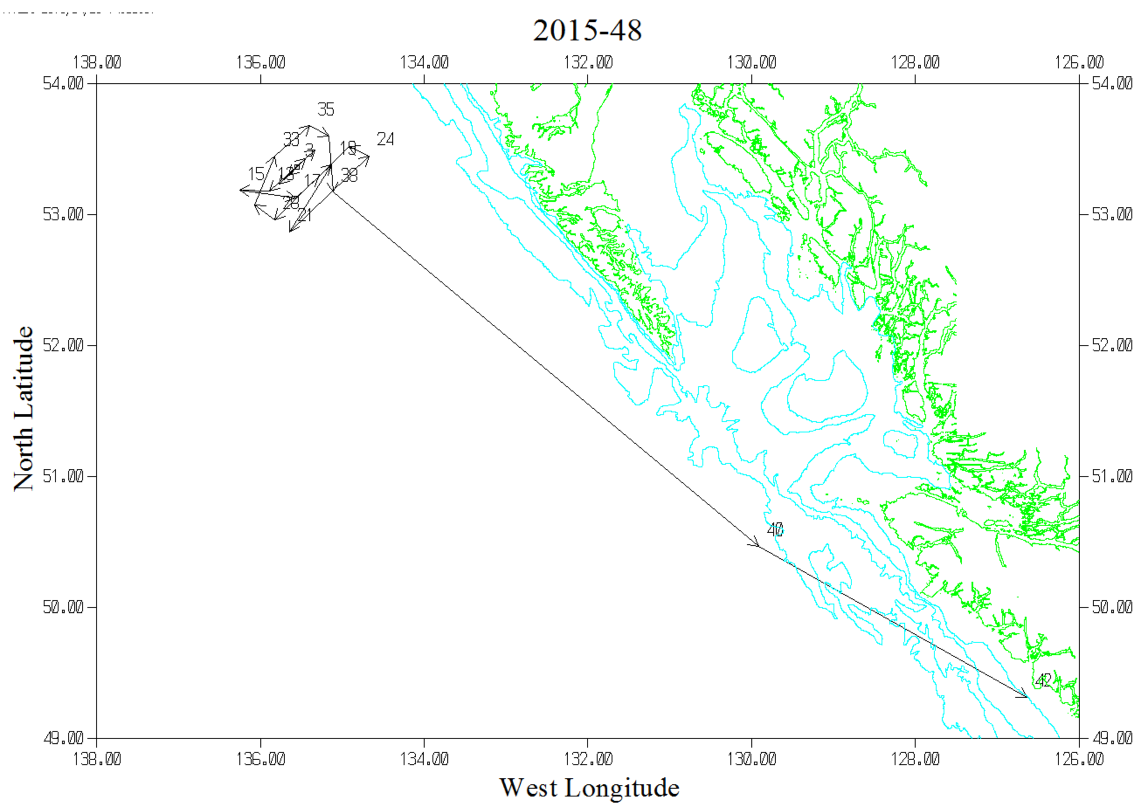


Figure 14. Event numbers from PAC 2015-48, as archived in the IOS data archive.

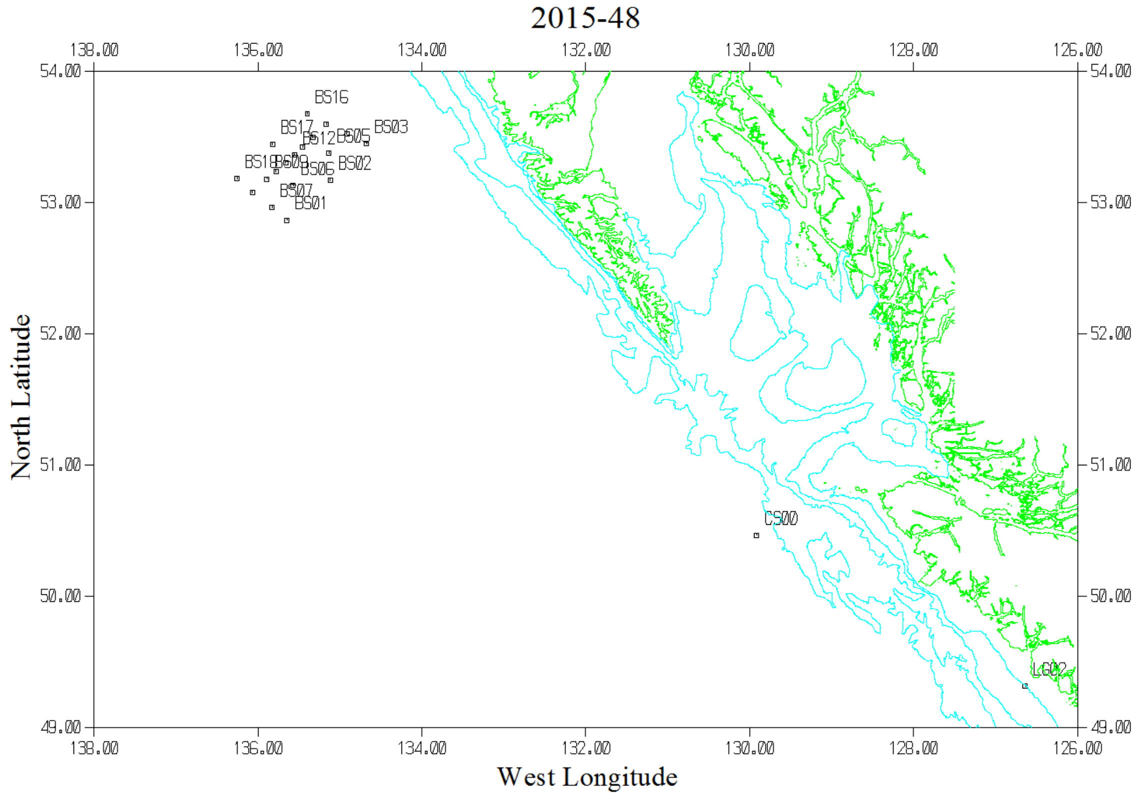


Figure 15. Sampling station numbers for SBE911+ files from PAC 2015-48.

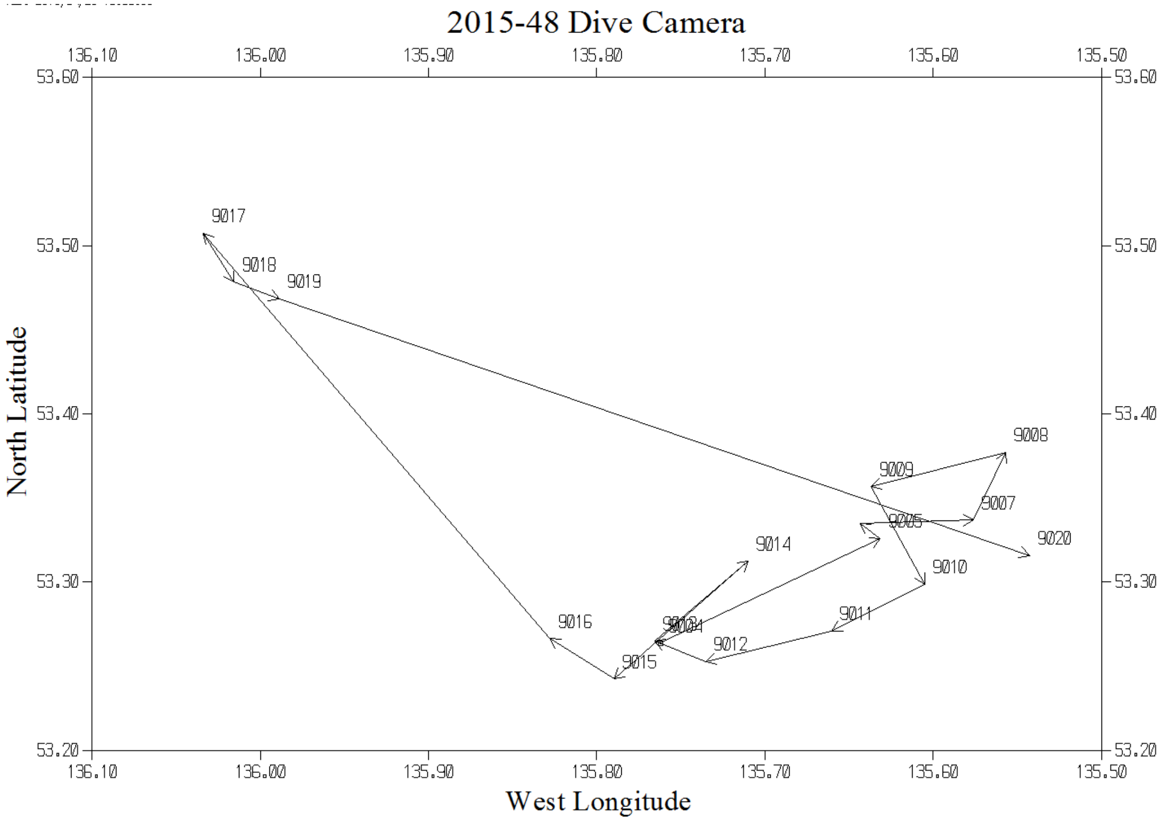


Figure 16. Event numbers for SBE25 files mounted with tow-camera system from PAC 2015-48.

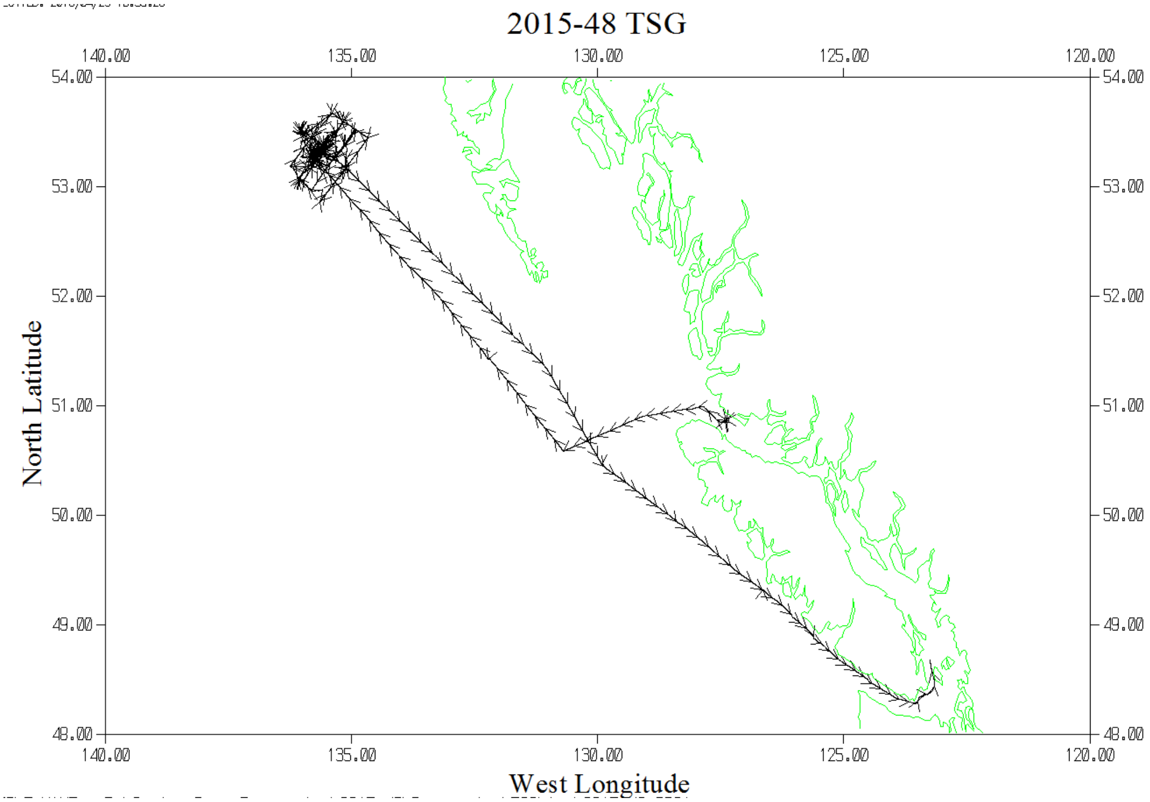
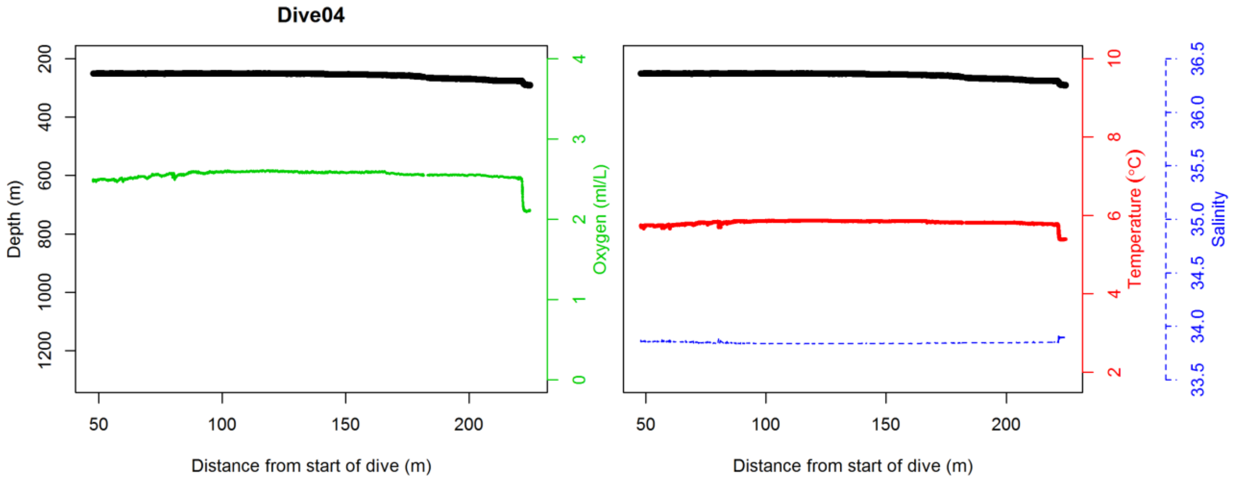
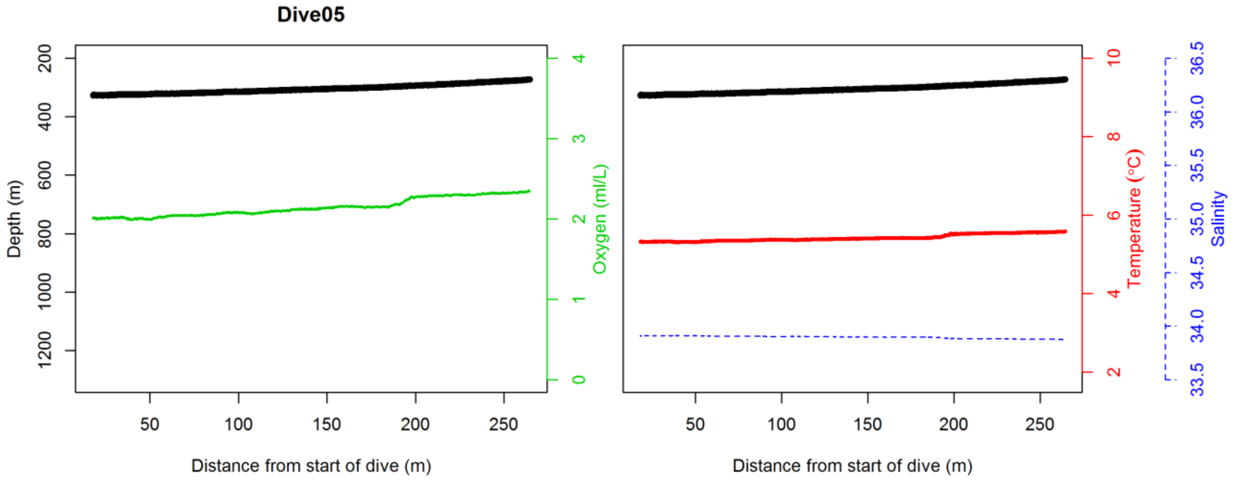


Figure 17. Thermosalinograph track for PAC 2015-48.

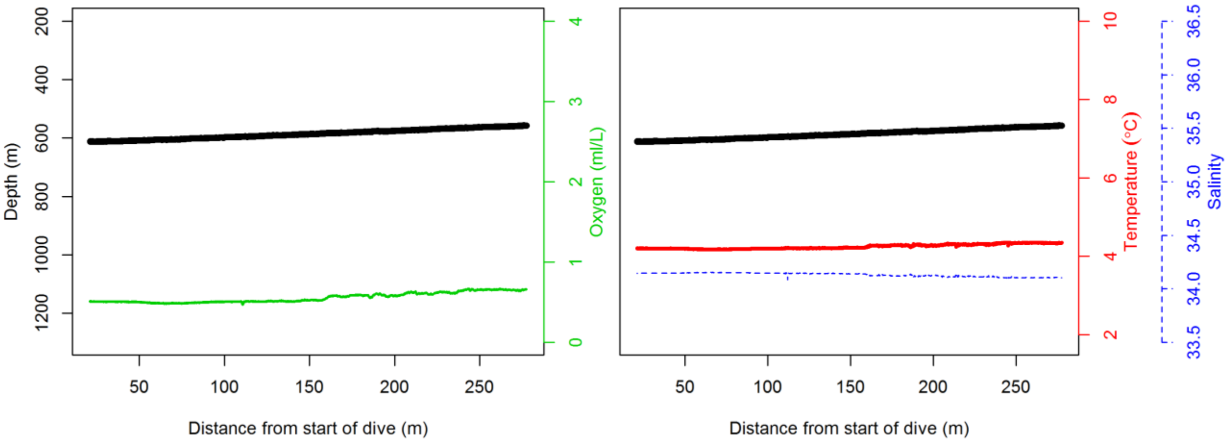
Appendix 8 – Depth and CTD profiles for tow-camera transects

The following figures show bottom depth along each transect, as well as oxygen concentration, temperature, and salinity for Dives 4–8 and 16–20 (no CTD data is available for Dives 9–15). The distance covered was measured using the A-frame tracking for all dives. Depth is from the CTD for Dives 4–8 and 17–19, from the BOOTS depth sensor for Dives 9–15, and from a combination of the two for Dives 16 and 20 (see Appendix 4 for explanation).

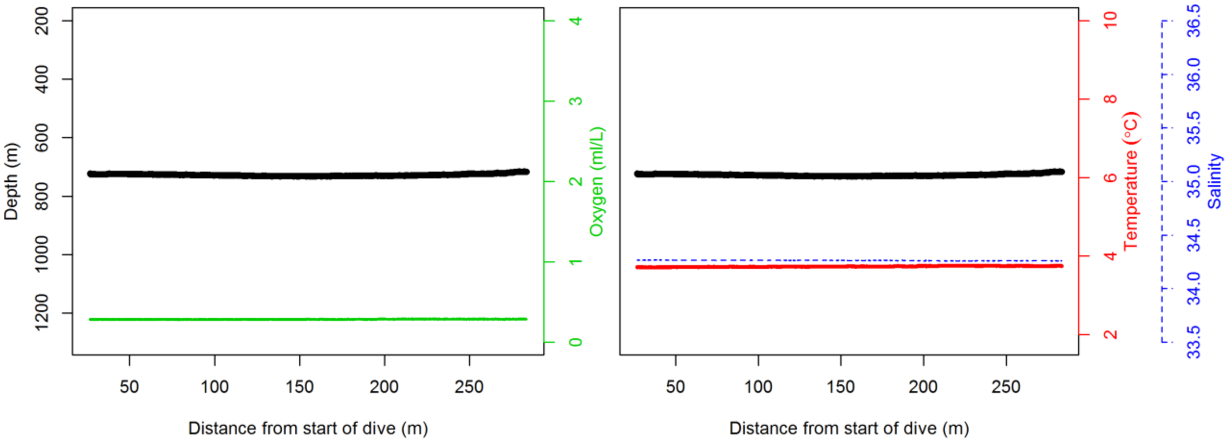




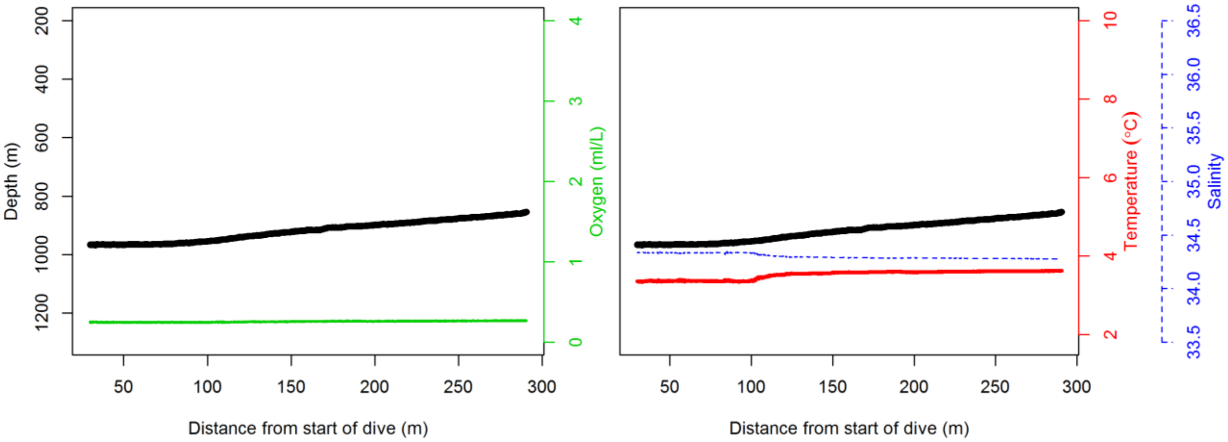
Dive06

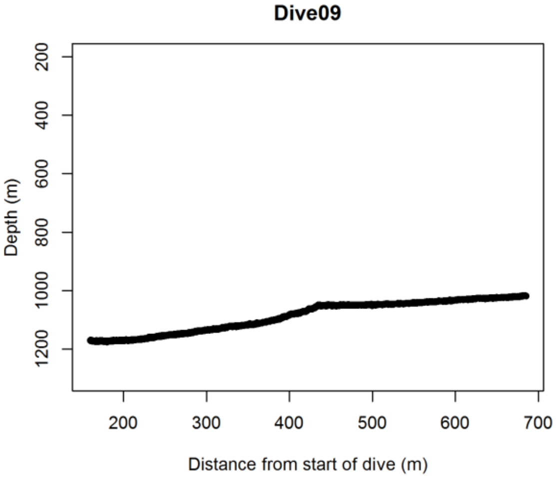


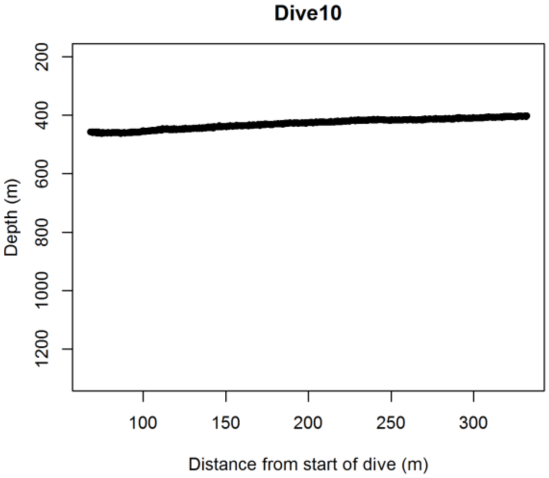
Dive07

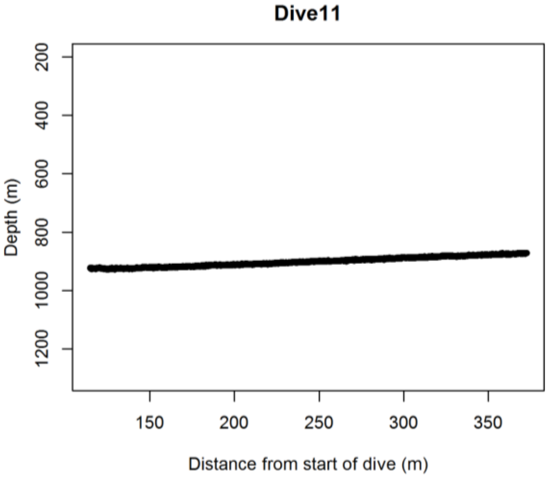


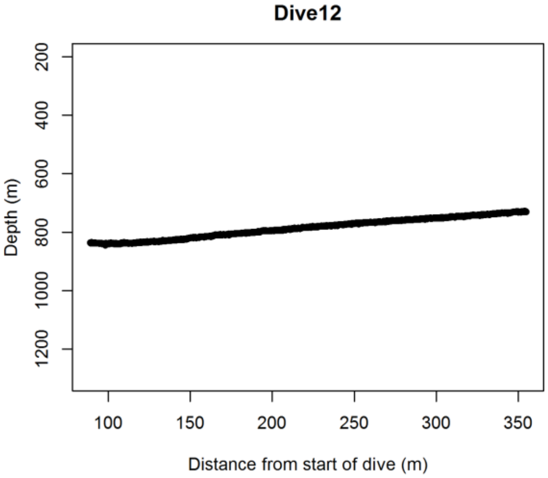
Dive08

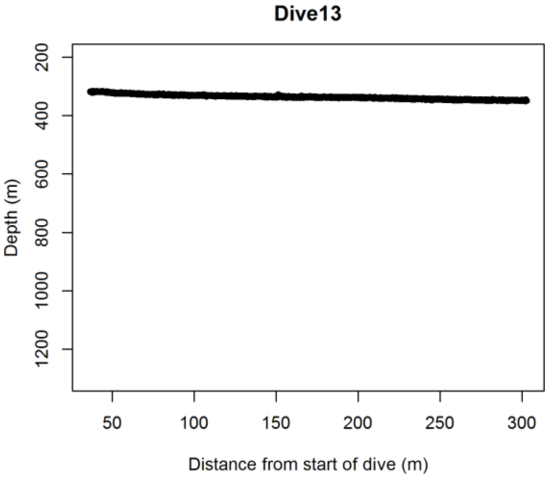


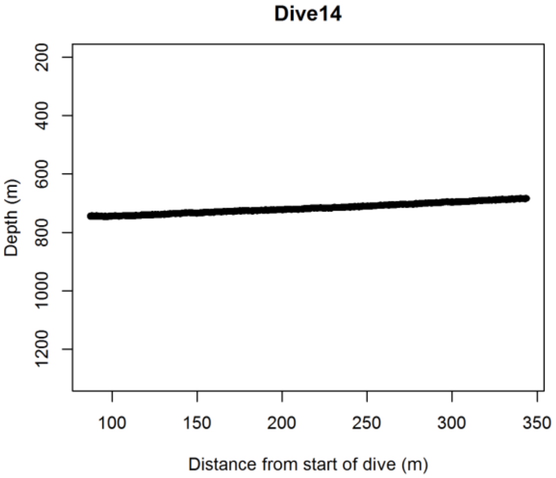

Dive09

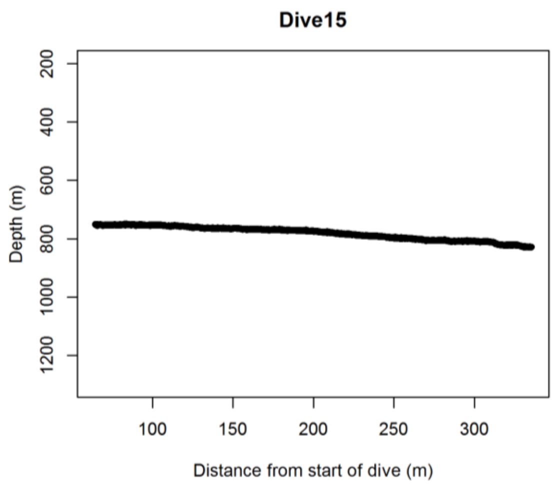

Dive10

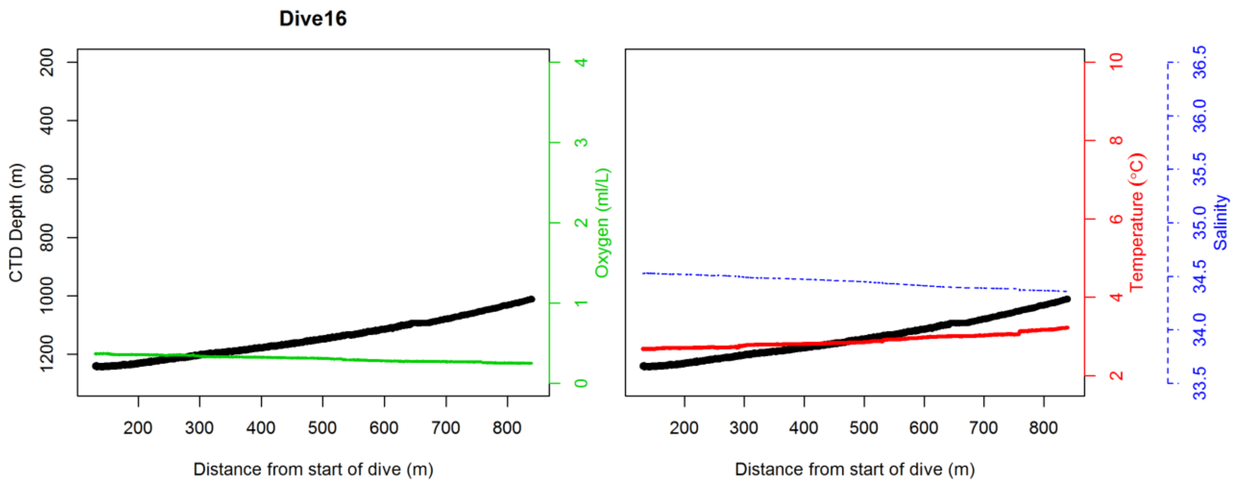

Dive11

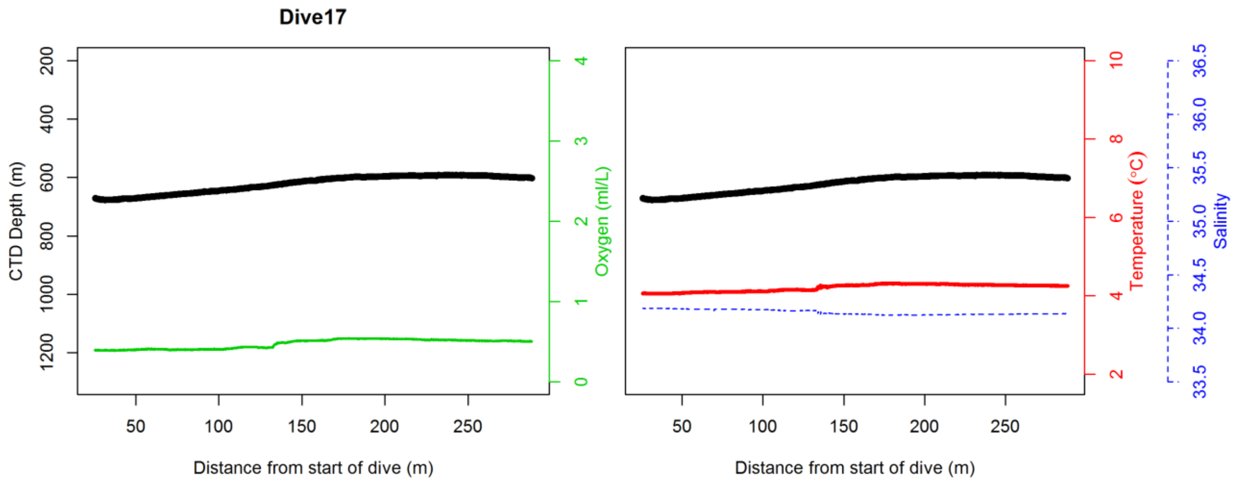

Dive12

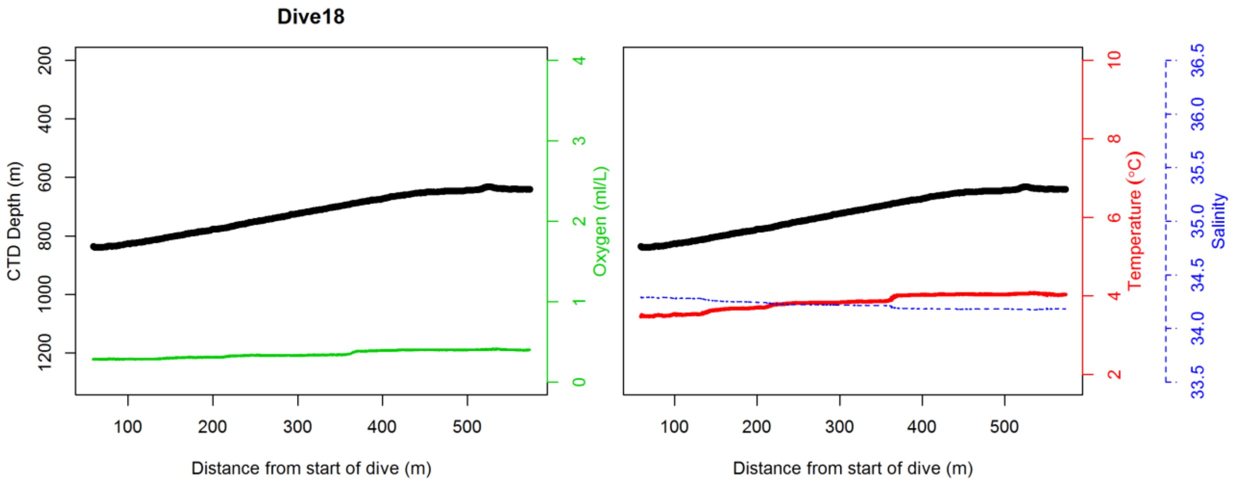

Dive13

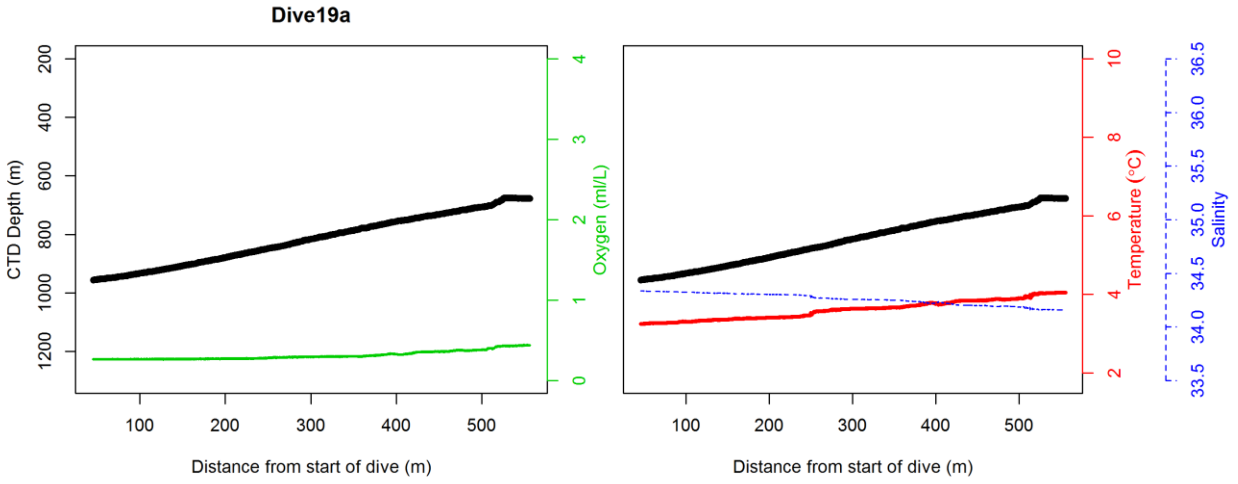

Dive14

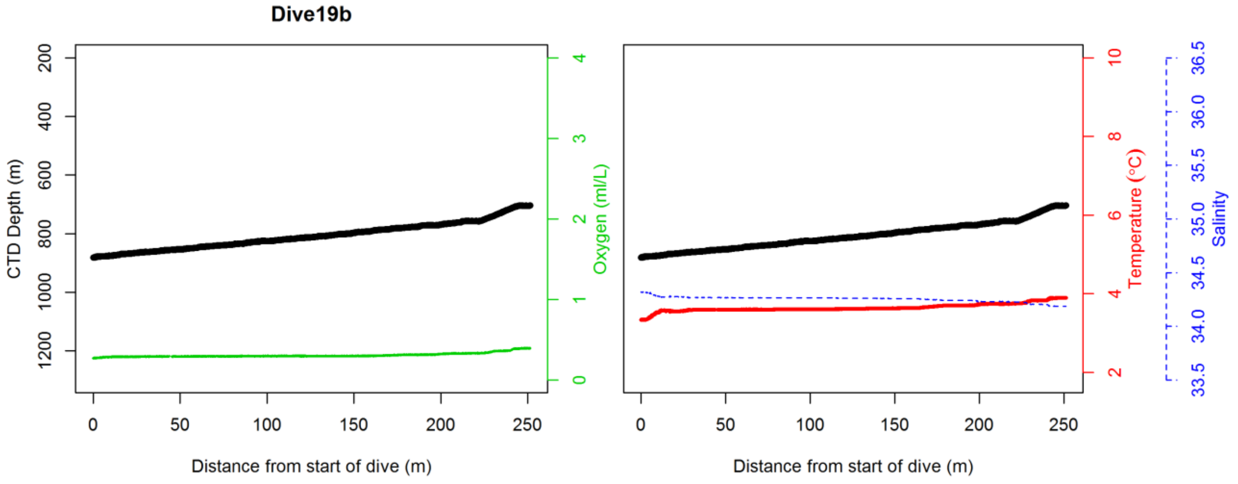

Dive15
Depth (m)
200
400
600
800
1000
1200
100
150
200
250
300
Distance from start of dive (m)

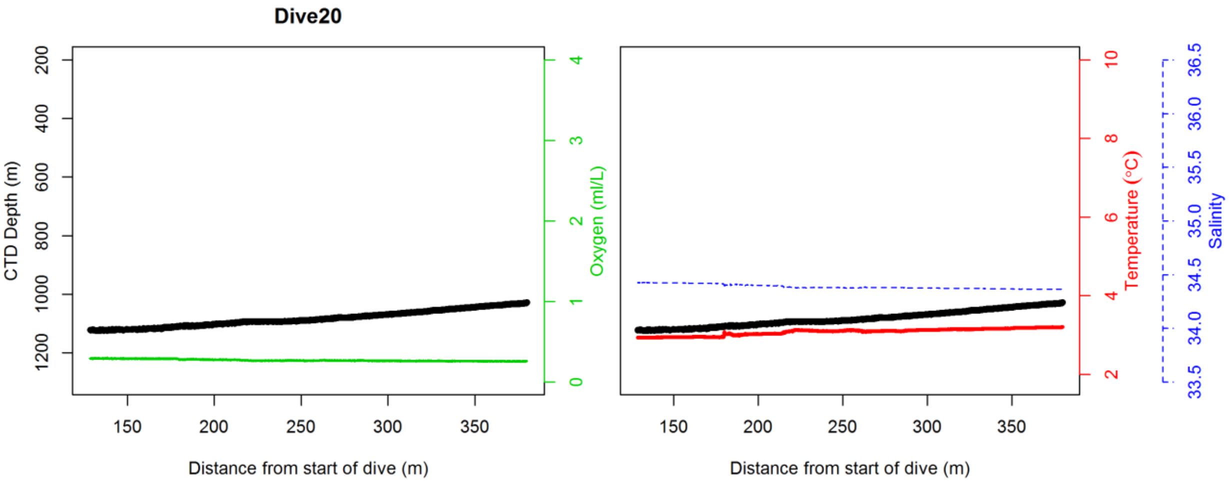

Dive16
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
200
300
400
500
600
700
800
Distance from start of dive (m)
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
200
300
400
500
600
700
800
Distance from start of dive (m)


Dive17
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
50
100
150
200
250
Distance from start of dive (m)
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
50
100
150
200
250
Distance from start of dive (m)

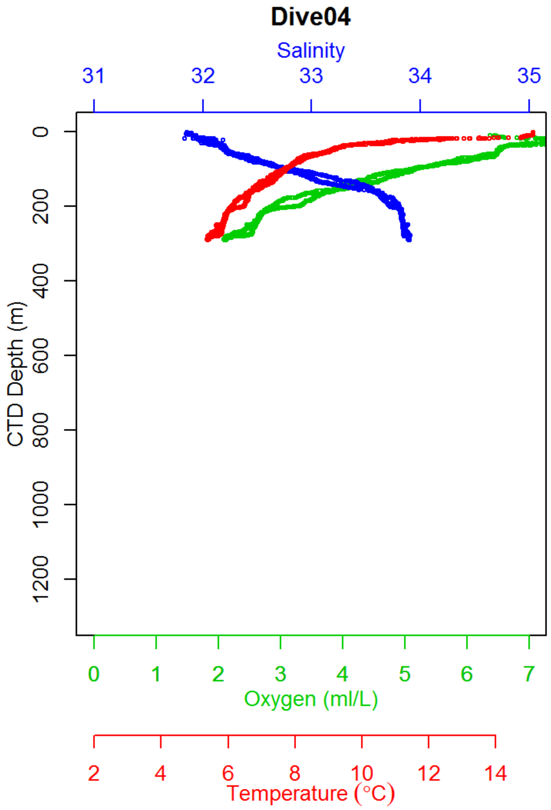

Dive18
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
100
200
300
400
500
Distance from start of dive (m)
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
100
200
300
400
500
Distance from start of dive (m)

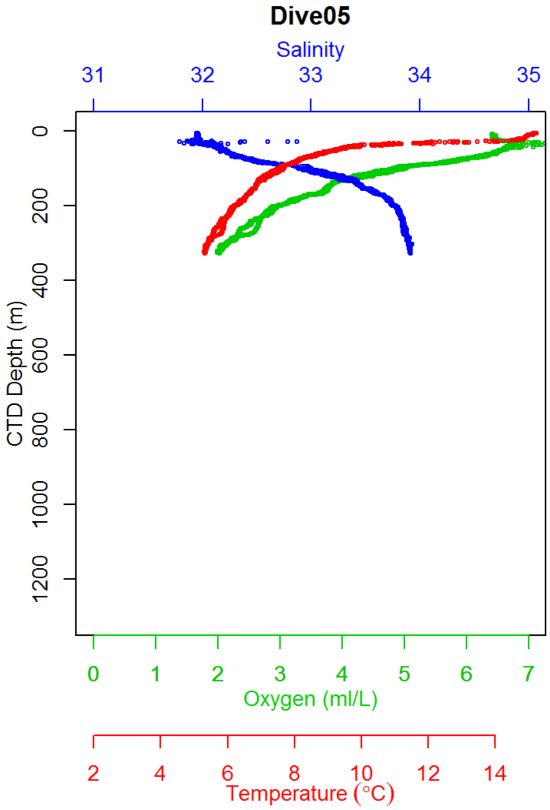

Dive19a
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
100
200
300
400
500
Distance from start of dive (m)
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
100
200
300
400
500
Distance from start of dive (m)

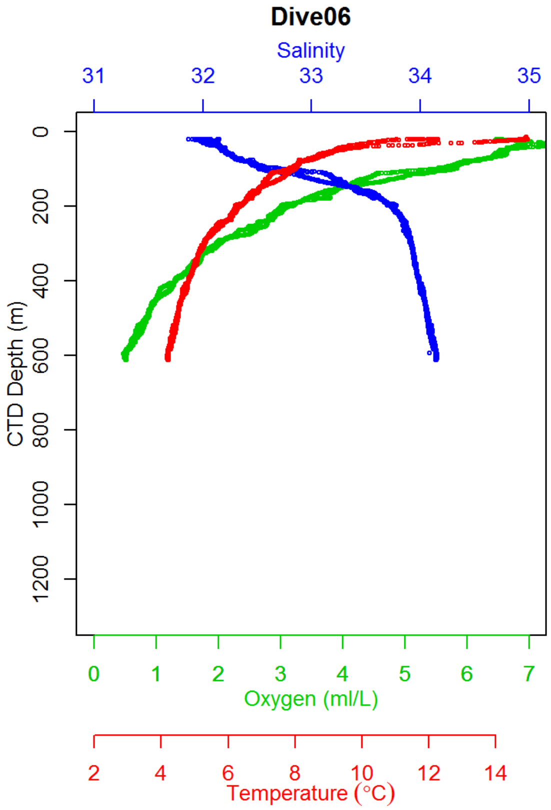

Dive19b
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
0
50
100
150
200
250
Distance from start of dive (m)
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
0
50
100
150
200
250
Distance from start of dive (m)

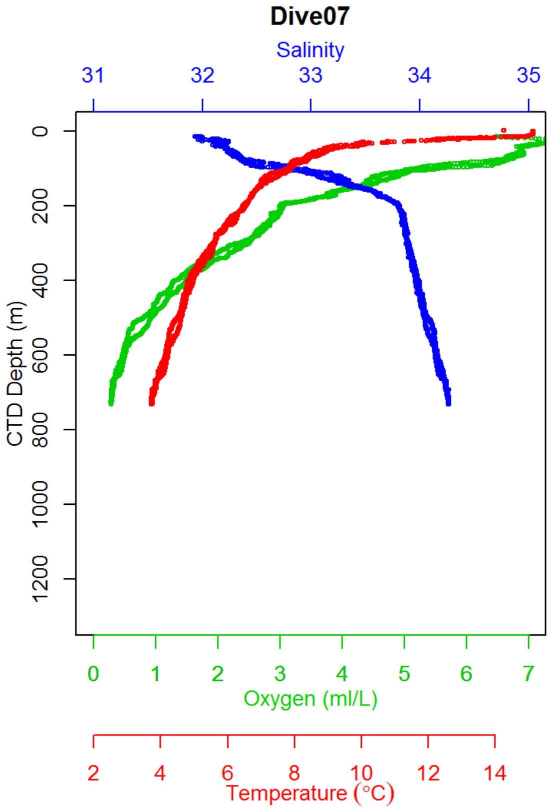

Dive20
CTD Depth (m)
200
400
600
800
1000
1200
Oxygen (ml/L)
0
1
2
3
4
Distance from start of dive (m)
150
200
250
300
350
Temperature (°C)
2
4
6
8
10
Salinity
33.5
34.0
34.5
35.0
35.5
36.0
36.5
Distance from start of dive (m)
150
200
250
300
350

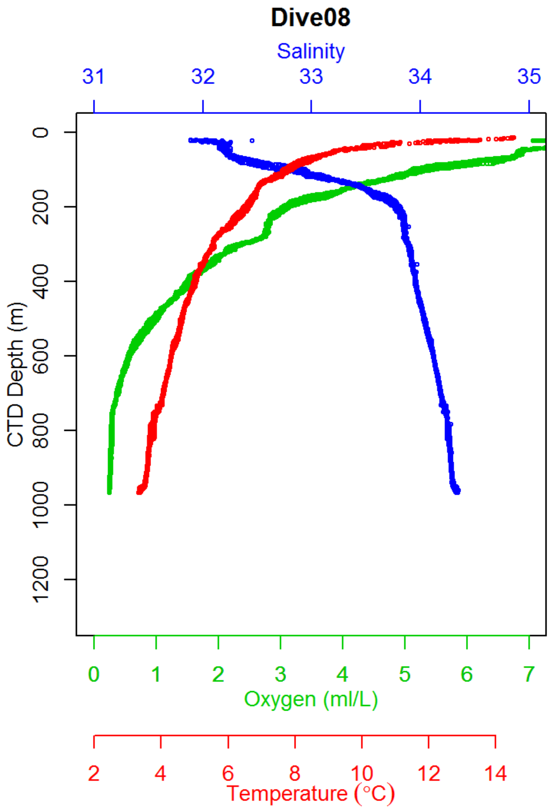
The following figures show oxygen concentration, temperature, and salinity by depth for Dives 4–8 and 16–20 (no CTD data is available for Dives 9–15).



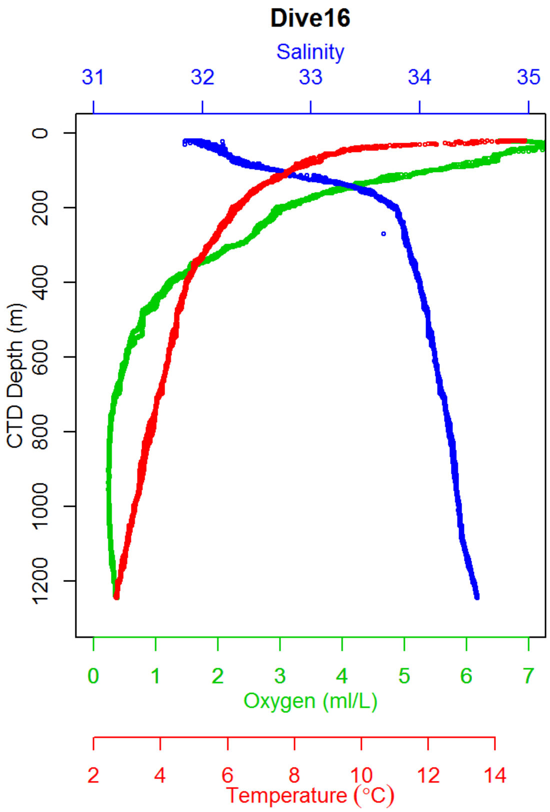




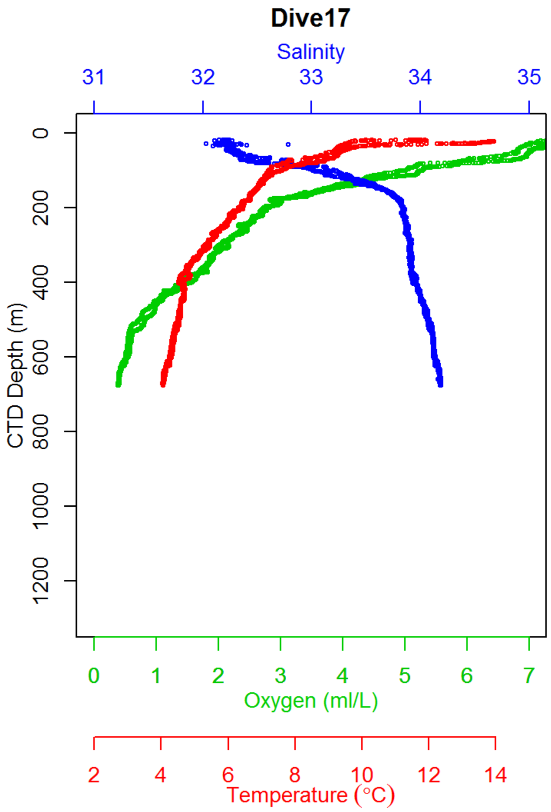




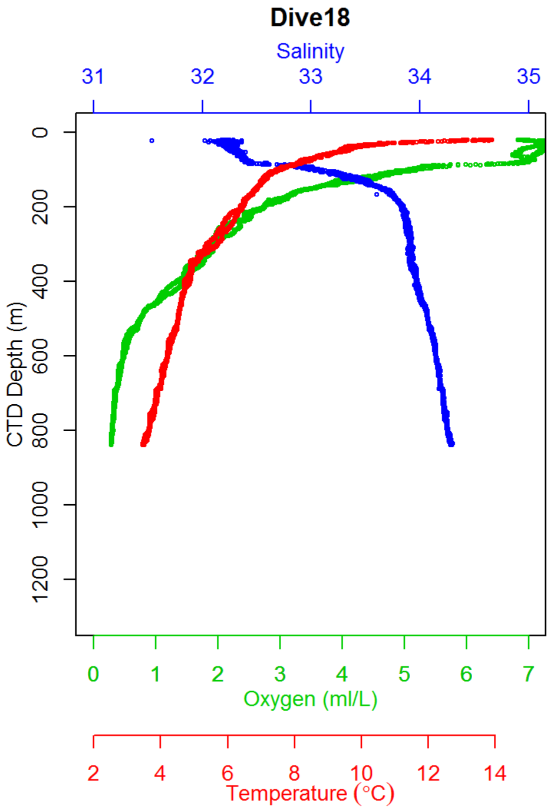
Dive08
Salinity
31
32
33
34
35
CTD Depth (m)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
Oxygen (ml/L)
2
4
6
8
10
12
14
Temperature (°C)



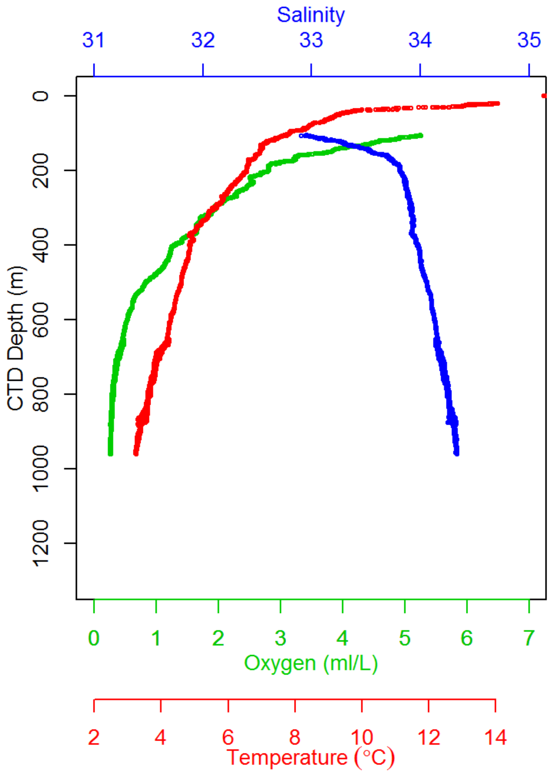
Dive16
Salinity
31
32
33
34
35
CTD Depth (m)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
Oxygen (ml/L)
2
4
6
8
10
12
14
Temperature (°C)

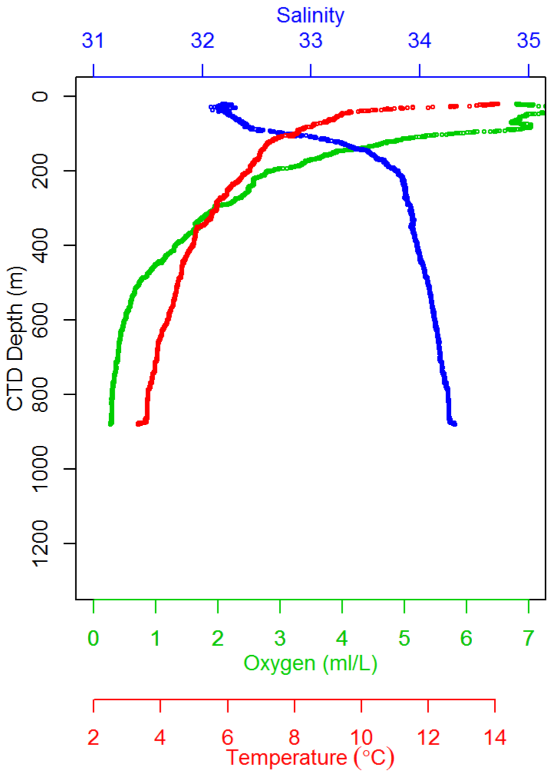


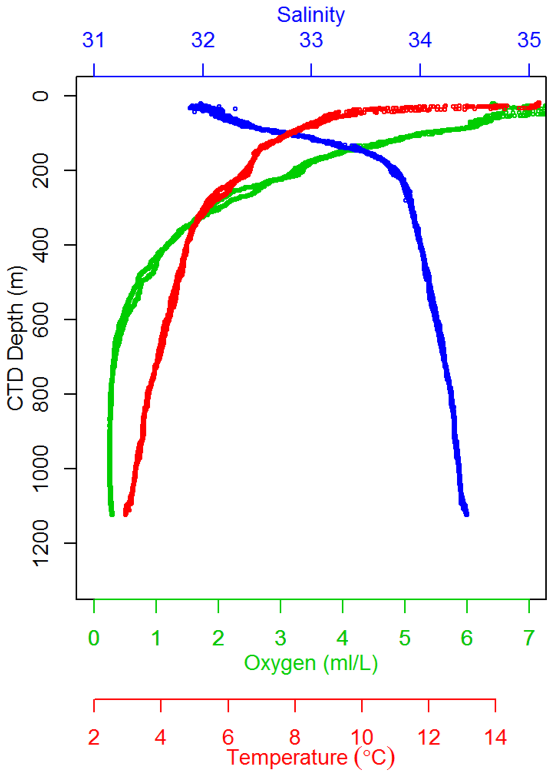
Dive17
Salinity
31
32
33
34
35
CTD Depth (m)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
Oxygen (ml/L)
2
4
6
8
10
12
14
Temperature (°C)



Dive18
Salinity
31
32
33
34
35
CTD Depth (m)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
Oxygen (ml/L)
2
4
6
8
10
12
14
Temperature (°C)


Dive19a


Dive19b


Dive20

Appendix 9 – Seabird species

Table 17. Common names, orders, families, genera and species of all marine-associated birds mentioned in text or tables. Taxonomy based upon BirdLife International Taxonomic Checklist v8.0 (October 2015) http://www.birdlife.org/datazone/info/taxonomy.

Common name	**Order**	**Family**	**Genus and Species**
White-winged Scoter	Anseriformes	Anatidae	*Melanitta deglandi*
Black-footed Albatross	Procellariiformes	Diomedeidae	*Phoebastria nigripes*
Northern Fulmar	Procellariiformes	Procellariidae	*Fulmarus glacialis*
Murphy's Petrel	Procellariiformes	Procellariidae	*Pterodroma ultima*
Pink-footed Shearwater	Procellariiformes	Procellariidae	*Ardenna creatopus*
Sooty Shearwater	Procellariiformes	Procellariidae	*Ardenna grisea*
Fork-tailed Storm-Petrel	Procellariiformes	Hydrobatidae	*Hydrobates furcatus*
Leach's Storm-Petrel	Procellariiformes	Hydrobatidae	*Hydrobates leucorhous*
Brandt's Cormorant	Suliformes	Phalacrocoracidae	*Phalacrocorax penicillatus*
Double-crested Cormorant	Suliformes	Phalacrocoracidae	*Phalacrocorax auritus*
Pelagic Cormorant	Suliformes	Phalacrocoracidae	*Phalacrocorax pelagicus*
Red-necked Phalarope	Charadriiformes	Scolopacidae	*Phalaropus lobatus*
Red Phalarope	Charadriiformes	Scolopacidae	*Phalaropus fulicarius*
South Polar Skua	Charadriiformes	Stercorariidae	*Catharacta maccormicki*
Parasitic Jaeger	Charadriiformes	Stercorariidae	*Stercorarius parasiticus*
Long-tailed Jaeger	Charadriiformes	Stercorariidae	*Stercorarius longicaudus*
California Gull	Charadriiformes	Laridae	*Larus californicus*
Glaucous-winged Gull	Charadriiformes	Laridae	*Larus glaucescens*
Sabine's Gull	Charadriiformes	Laridae	*Xema sabini*
Black-legged Kittiwake	Charadriiformes	Laridae	*Rissa tridactyla*
Arctic Tern	Charadriiformes	Laridae	*Sterna paradisaea*
Common Murre	Charadriiformes	Alcidae	*Uria aalge*
Marbled Murrelet	Charadriiformes	Alcidae	*Brachyramphus marmoratus*
Ancient Murrelet	Charadriiformes	Alcidae	*Synthliboramphus antiquus*
Cassin's Auklet	Charadriiformes	Alcidae	*Ptychoramphus aleuticus*
Rhinoceros Auklet	Charadriiformes	Alcidae	*Cerorhinca monocerata*
Horned Puffin	Charadriiformes	Alcidae	*Fratercula corniculata*
Tufted Puffin	Charadriiformes	Alcidae	*Fratercula cirrhata*