Bangarang Methods
(Season Two)

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1 Bangarang Backgrounders are imperfect but rigorous reviews – written in haste, not peer-reviewed – in an effort to organize and memorize the key information for every aspect of the project. They will be updated regularly as new learnin’ is incorporated.

2 Ideally, duplicate tows at the Whale Point, Fawcett Point, and north Campania stations.
Study Area
Kitimat Fjord System

The study area (1,220 km$^2$ of water, Fig. 1) is located within the Kitimat Fjord System (KFS) of northern mainland British Columbia, centered at 53°N and 129°W. The KFS comprises the territory of the Gitga’at First Nation, the confined channel portion of the area’s proposed tanker highways, Fisheries Management Area (FMA) 6 for the BC coast and the acoustic study area of the North Coast Cetacean Society (NCCS, my principle collaborators).

The KFS occurs in a remote section of the coast that has received little study relative to fjord systems to the north (southeast Alaska) and those to the south (e.g., Knight Inlet, BC). Kitimat, the port at the head of the fjord system, has been targeted for industrial development since the 1970s (Narayanan 1980). As a result some physical oceanographic surveys have occurred in the area with emphasis in Douglas Channel (Narayanan 1980, MacDonald et al. 1983, Fissel et al. 2010). Studies in the rest of the KFS were rare until 10 years ago, when NCCS began monitoring whale activity and new proposals for the port of Kitimat (e.g., Enbridge 2010) called for baseline studies.

Inland waterways of the KFS are compartmentalized by channel constrictions (e.g., seafloor sills) and bear a steep-walled morphology typical of BC fjords (Pickard 1961, Pickard 1967, MacDonald et al. 1983). Mean channel depth is highly variable but all are deeper than the adjacent continental shelf in Hecate Strait. The channels of Gil Basin (Squally, Wright and Whale) are among the deepest inlets on the coast (MacDonald et al. 1983). As Syvitski et al. (1987) put it, fjords are “perfect natural oceanographic and geologic laboratories. Source inputs are easily identified and their resulting gradients are well developed”.

The system occurs in the Kitimat Coastal Ranges of the Great Bear Rainforest, the largest temperate coastal rainforest in the world (Thompson 1981). Its 29 watersheds (Fissel et al. 2010) result in its classification as a high-discharge system. This runoff establishes a classic estuarine circulation (seaward surface flow countered by landward bottom current) with strong surface salinity gradients inshore to offshore (Freeland and Farmer 1980, MacDonald et al. 1983). The area’s perennial estuarine circulation is modulated by punctuated events of wind-driven circulation (e.g., from katabatic outflows) and strong tidal currents, all of which exhibit strong seasonal signals (MacDonald et al. 1983).

The study area’s climate ((Fissel et al. 2010), terrestrial botany (People of the Gitga’at First Nation 2006), intertidal community (Turner et al. 2003) and zoogeography exhibit strong offshore-inshore gradients. My preliminary results suggest similar trends in seabird and marine mammal distributions (Figs. 3 & 5).

**Backgrounders:** “BC Coast”, “Fjords!”, “The Gitga’at First Nation”, “Natural History of the Great Bear”.

Figure 1. Study area.
Methods Summary

My overarching questions can all be answered by building off of the same general sampling design.

Repeated circuits of the study area will be conducted during three summers using the SV Bangarang, a 1980 Cooper Seabird 37’ motorsailer. I am the owner and operator of this vessel, which makes the project cost-feasible.

A research circuit is split into eight geographic blocks (Fig. 2). Each block is surveyed within a single day, so a circuit requires 8 to 14 days with weather delays. We alternate between “oceanographic” circuits, in which stations are visited, and “predator-prey” circuits, in which only transects are conducted and close approaches with whales are prioritized. For 2014 our target is 8 circuits, 4 of each mode.

Stations

During oceanographic circuits we (2 crew and I) visit a grid of stations (n=24, or 3 per block) between which we conduct concurrent visual and acoustic surveys.

At each station we perform a CTD cast (to 100m) and Secchi disk reading. Three plummet-style zooplankton tows (333u, 0.7m diameter, OAR 6:1, flowmeter- and strobe-equipped, dropped to 250m) are taken at the stations within each block. To accommodate variable weather, swell and whale conditions these tows can be distributed amongst a block’s stations as needed (i.e., all three tows for a block can occur at one station if need be). Samples are preserved in 5% formaldehyde-seawater solution.

In addition to systematic daytime sampling, six replicate tows will occur at stations in the center of the study area\(^2\) as close to midnight as possible. This area was chosen for its central location, its protection on all sides from weather, its options for anchorage and the fact that both fin and humpback whales focus foraging efforts there.

Transects

While underway between stations, four surveys are conducted concurrently. All data are recorded using a data entry program (DEP) I wrote for touchscreen laptops to accommodate the rapid entry of many forms of data.

1. **Hydroacoustic transects** with a Syqwst Hydrobox echosounder (33 and 200 kHz dual-beam) to obtain a map of the ambient depth, distribution, and patchiness of backscatter down to 500m (200m for high-frequency) that is synchronized and geo-rectified with sighting and effort data from visual surveys.

2. **Non-systematic passive acoustic transects** with a towed array (2 hydrophones, 3m separation) custom built for monitoring low- and mid-frequency cetacean vocalizations. The array will be deployed when conditions allow and always within visual range of whales. Three back-up recording systems will be on board in case we experience equipment malfunctions.

\(^2\) Ideally, duplicate tows at the Whale Point, Fawcett Point, and north Campania stations.
3. **Visual surveys for cetaceans** using distance sampling methodology. Bearing and reticle readings for each sighting are taken using Fujinon 7x50 binoculars. At standard intervals observers rotate between three positions, one of which is data entry at the helm. A weather station mounted 5m high records air temperature, barometric pressure, and wind speed and direction at one-minute intervals. Sea state and sighting conditions are logged in the DEP hourly or as they change.

4. **Visual surveys for seabirds & pinnipeds (et al.)** using strip-width methodology. Within 150m of each side of the vessel (gauged using handheld rangefinders), we collect data on all seabird sightings as well as near-surface occurrences of plankton, fish, and oceanographic features (e.g., accumulated debris indicative of frontal zones).

**Close Approaches**
When whales are sighted, transect effort is suspended and focal follows are commenced. Effort is considered “with-whales” when we are within 150m of groups. During these encounters, the team collects respiration intervals, travel patterns, group composition, identification photographs, behavioral notes, fecal and prey samples where possible, and acoustic backscatter. Special effort is made to observe and document notable feeding events, especially multi-species “bait balls” and interactions among predators in the event. We use fine-mesh skimmers on long poles, cast nets, and photographs to collect prey, feather, scat and skin from these bait ball events. These samples are preserved in alcohol to make isotope and DNA analysis possible.
Vessel

The SV Bangarang is a Cooper Seabird 37’ (12 m) center-cabin cutter. This is within the ideal size range (10 to 20m) for high quality line-transect surveys from smaller vessels (Dawson et al. 2008). Low-cost vessels are good for coastal research because they allow (i) much more survey effort to be expended for the same cost, (ii) surveys to be conducted in better sighting conditions (since vessel costs are low, you can afford to wait), and (iii) a significant amount of vessel time can be spent on observer training (Dawson et al. 2008). When conditions allow, sailing vessels also enable you to collect visual and acoustic data without the disturbance of engine noise (Fig. 3c). Motorsailers are not an uncommon platform for cetacean research (e.g. Papastavrou et al. 1989, Gordon et al. 1999, Dawson et al. 2008), including fin whales studies (Panigada et al. 2005).

The Bangarang was built in Port Coquitlam, British Columbia in 1980. Eric renamed it Bangarang and imported it into the U.S. in 2013 and is now documented with the USCG. Her 3/4 keel draws 4.0 ft, her displacement is 18,000 lbs, and her cruising speed is 6 knots at 0.68 gal/hr. Her hull speed is approximately 6.6 knots. Her 1980 Perkins 4.108 diesel engine has 45 hp at 2200rpm, and an estimated 3,000 hours as of November 2013. Both her diesel and water tanks are 120 gallons. Her 3-blade prop is enclosed by the keel and a keg-hung rudder, provides protection against fouling in kelp and renders her a relatively safe vessel for close whale interactions. Her 2013 anchor system includes 89’ of high-test G4 3/8” chain, 200’ of 7/16” double-braided nylon, and a 54 lb. Bruce-type anchor retrievable with a manual windlass at the bow. The battery bank includes two flooded deep-cycle lead-acid 12V batteries, one dedicated for starting the engine and the other used primarily for house electronics. Batteries are charged underway by a 70-amp Balmar alternator with an external multi-stage regulator (new 2013). The Bangarang has a dedicated 12V AGM research battery (2013), capable of isolation from other electronics and the engine, which ensures clean signals to sensitive acoustic instrumentation. Two inverters, one 1200-Watt pure sine wave and the other 1550-Watt square wave, power AC electronics while underway. There are three VHF radios on board, an iCom 2200H (2103), a Standard Horizon unit (2013), and a handheld iCom. Navigation electronics include a Garmin 441s chartplotter/depthsounder and a Furuno 1623 radar system (both new 2013). Sail inventory includes a mainsail (original), staysail (original), yankee jib (2007), and a spare genoa (original). Headsails furl on a Cruising Designs roller furler. The mainsail is contained by a Doyle Cradle Cover and lazy jacks system (new 2013). Numerous improvements have been made to the Bangarang in the first year of this project (see 2013 Report).

The vessel also features a cockpit fully protected by a dodger and bimini (new 2013), stateroom, kitchen, dinette, salon, and two heads. A 2013 8ft inflatable tender/liferaft, the Jangan Gila Dong II, is stowed onboard the aft swimbridge (Fig. 3d). Bangarang sleeps 3 quite comfortably, 4 comfortably if two are a couple, and 5 if needed. The aft head has a semi-functional shower. Engine-heated water flows to all faucets on board. The kitchen has an icebox and a gimbaled stove; propane is stored under the helm seat in the cockpit. The water heater can use both the running engine and shorepower to function. An Espar heater provides forced-air ventilation for all cabin areas. The 4-speaker JVC KD-X200 stereo was new in 2013, and is used for live playback of hydrophone recordings. The Bangarang has a top-knotch library of regional natural history field guides, whale-oriented literature, adventure classics, sailboat maintenance manuals, and scientific publications. Her map drawer contains charts that cover the entirety of the southern Inside Passage in detail, from Olympia to Prince Rupert. Song books are also on board, and a ukelele, guitar, and banjo are stowed on the walls and ceiling of the salon with quick-release lashings. Harmonicas (keys G, C, F, D, and A) are also on board, along with a hands-free holder. Box wine and 20lbs of dark chocolate are stored under the salon’s settees.
Stations

Stations were spaced in a pseudo-homogeneous distribution. Their placement was informed to a degree by logistics (e.g., position relative to viable anchorages, protection from prevailing winds, etc.), which is an inevitable feature of working from a small vessel in a remote area. Nevertheless, stations were positioned randomly with respect to oceanography (Fig. 4). As such, they occur at a variety of depths and proximities to shore. This layout should representatively sample both the physical structure of the study area's water column and the diversity and relative abundance of zooplankton. At each station, we record Secchi depth and a CTD profile of the upper water column. This aspect of station work can take as little as 8 minutes with coordinated effort. Both the Secchi disk and the CTD are weighted with two 1-kg fishing weights each to reduce the effect of wind and lateral tidal drift.

CTD

To get a profile of the temperature, salinity and density of the upper water column (100m depth), we use a YSI Castaway CTD. The CTD is paid out using the same line used by the zooplankton net (see below). The unit is turned on before we reach the station in order to give the unit time to acquire a GPS position to associate with the cast. The CTD is allowed to free-fall to 100m then is retrieved by hand at approximately 1 meter per second.

Water Clarity

To obtain an index of water clarity, we use a classic 20-cm diameter Secchi disk. Secchi depth readings can be used to calculate optical properties (reviewed in Preisendorfer 1986, Effler 1988, Davies-Colley and Vant 1988, Davies-Colley and Smith 2001, and Hou et al. 2007). In bodies of water where plankton are the primary cause of turbidity, Secchi depths can provide an estimate of plankton density (Almazan & Boyd 1978). Seabird distribution (both plunging and pursuit-diving seabirds) may be influence prey visibility/accessibility (Ainley 1977, Safina & Burger 1988) -- but it also may not (Haney and Stone 1988) or turbidity may only matter for certain taxa (Henkel 2006).

The disk is dropped on the sunny side of the boat (which allows more optical properties to be calculated from the reading; when it is overcast the southern side of the boat is used; Smith 2001) and viewed through a viewerbox (after Davies-Colley 1988, Smith and McBride 1990, Smith et al. 1997 and Smith 2001). Viewer boxes increase between-observer precision by removing the interfering effects of water surface glare and glitter (Smith 2001). The viewerbox is a large black-plastic pipe with handles. The wet-end is sealed with clear plastic and the viewing end is trimmed with neoprene to ensure a good seal around the eyes (after Smith 2001). The weighted Secchi disk is suspended from a tape-measure reel that is fed through an eyebolt on the bottom of the viewerbox.

Each observer takes a reading and records their finding without colluding with others. Eyes are given 20 seconds to adjust before a reading. Readings are taken from the top stern rail at the same distance fore of the transom. The Secchi depth is defined as the exact depth of disk disappearance (as in Smith 2001). If the drop angle is greater than ~15 degrees, the angle is noted as “slight” in the data entry software. If it is greater than 30 degrees, it is noted as “acute” (this never happened in 2013).

The three readings for each station will lend insight into observer error in the Secchi depth measurements. Eric will also do a Secchi disk reading at each station without the viewerbox to test for box effects. It is possible that the variation in Secchi depth observed among stations within and among blocks is less than that among observers at a single station. To address this, a trial was conducted in 2013 in which 3 observers made 24 casts each while docked in 30m of water in Barnard Harbor, an anchorage centrally located in the study area at the southern end of Whale Channel, during which sea state and cloud cover conditions remained constant. Observer differences introduced the most variability to readings. Within-observer variability was very low. The use of a viewerbox in 2014 and 2015 (and the fact that Eric will be a constant observer in all three years) should increase precision among observers. Furthermore, at the end of the study, the influence of external factors such as sea state and cloud cover can also be assessed using all casts from all seasons.
Water Color

Color of seawater is recorded with the numbered Forel-Ule color scale (Sverdrup et al. 1942) using the white background of a Secchi disk (after Haney and Stone 1998, Wernand & Woerd 2010). The Forel-Ule (FU) scale is a color comparator scale with tints varying from indigo-blue to cola brown to quantify the color of natural waters. It is a method recommended for use in marine settings (Wernand & Woerd 2010). The scale is held above the sea surface within a shadow and the operator looks down on the water through an observation windows next to each tube. The best match between the color of the water column and one of the tube-colors is determined and is documented as an integer number representing the FU scale equivalent.

Zooplankton

Day Plummets

Three tows are taken at the stations within each block. To accommodate variable weather, swell and whale conditions these tows can be distributed amongst a block’s stations as needed (i.e., all three tows for a block can occur at one station if they must). Samples are preserved in 5% formaldehyde-seawater solution.

To design for the Bangarang Project’s goals within our constraints, we planned for daytime vertical tows with a plummet net (after Bartle 1976, Bradford 1977, Heron 1982, Daly & Macauley 1988 and Hovekamp 1989, among others). A plummet net is a down-fishing zooplankton sampler that has no mouth obstructions and is cinched shut when the desired depth is reached. Because the plummet net falls quickly, vertically, and begins sampling immediately once it hits the water, the problem of drift in strong currents is minimized; the boat may drift in relation to the net, but the net remains relatively stationary with respect to oceanography. The design was first described in detail by Heron (1982). The elements I am contributing to Heron’s (1982) original published design are as follows.

1. The choke line connects to the tow line at both ends, providing a quicker and more reliable “dual-action” choking motion.
2. A fixed-length line runs from the ring to the shackle that joins the choke line to the tow line. This line serves as both a safety and as a limit to how tightly the Dacron can be choked, increasing the longevity of the net material.
3. A new cod-end design that allows the net to be dangled and prepare alongside the research platform before a drop.
4. Strength-bearing webbing running the length of the net, so that net can be suspended by the cod-end during preparation and sample preservation.
5. A mouth ring with spare eyebolts welded vertically at each quadrant, for mounting the flowmeter, adding weight and/or using the net with a bridle as an oblique sampler if needed.

The net itself was manufactured by Aquatic Systems Designs specifically for this project. The cylindrical portion of the net is non-porous black Dacron cloth, 70cm long. An elliptical band of webbing with nine equally spaced stainless steel caribeners runs from the mouth of one side of the Dacron to its opposite cone-ward side; these caribeners act as leads for the net’s choke lines. The conical section is 333 micrometer Nitex, 280cm long, for a total net length of 3.5m. 3 bands of strength-bearing webbing run the length of the net and extend beyond the 3.5” diameter cod-end by 18”. These webbing bands terminate in 1” diameter stainless D-rings, which are held collectively by a large stainless caribener. The net is suspended by this caribener when being staged for a drop

The 70cm-diameter mouth ring (area= 0.38 m²), made of solid ¾” 316 stainless steel, was manufactured at the SIO machine shop with 1/2” eye rings welded (with perpendicular orientation to ring, for hydrodynamics) at each quadrant of the ring, such that a bridle can be readily attached and used as a classic WP-2 oblique-tow net if needed. The ring weighs approximately 30 lbs. Retrieving the net manually is therefore difficult, especially when a moderate wind opposes a strong current. In 2013 all three researchers on board had to take turns pulling up the line. In 2014, a motorized line hauler will be added to the Bangarang.
The porosity of our 333-micrometer mesh is 66% (according to the Dynamic Aqua website). Assuming a 100% sampling efficiency (which is a conservative estimate for a cyl-cone net, Tranter and Smith 1968), and given that a typical effective drop depth is 200m (seafloor depth permitting), the Heron-Bangarang net’s median sample volume in 2013 was calculated to be about 70 m³. Unfortunately, in 2013 Eric broke the calibrated flowmeter graciously loaned by the Scripps Pelagic Invertebrate Collection while trying to protect it in a hard-foam Pelican Case. When the case was clamped shut, the device was crushed. For 2014, two flowmeters will be calibrated, safely packaged and used in the field. These two meters will also be used to test filtration efficiency in situ.

The cinching of the net upon retrieval should halt flowmeter spin. Sample volumes calculated from the flowmeter can be checked against expected values given messenger rope payout and drop duration.

To prevent clogging, a net designed for this tow duration in green waters must have an Open Area Ratio (OAR) of 5.4:1 or greater. Our net design has an OAR of approx. 6.5:1. Clogging was not observed in any 2013 tow. See the “Designing Nets” Backgrounder for more information.

In 2014 a 1000-Lumen strobe light was added to the net to bamboozle krill (after Sameoto et al. 1993, Weibe et al. 2004), whose avoidance significantly detriment the consistency and quantity of sample data. The light is a compact LED used in mountain biking and placed within a water-proof case designed for housing Go-Pro cameras (1000ft. depth rating).

As the net descends, zooplankton are coalesced into the 3.5” OD two-piece cod-end bucket loaned from and designed by the SIO PIC. The two pieces are connected by quick-release butterfly shackles. 1”-diameter drainage holes with 333-micron mesh are drilled into its sides. For added security, the removable end is attached with a caribener to a thin line streaming from the net’s webbing tails. This line also prevented the choke line from cinching entirely, keeping strain on the Dacron and mesh to a minimum. In 2013 a back-up net was also kept on board (333 micron, 0.7m diameter, 9:1 open-area ration, loaned from SIO PIC).

A concerted effort was made to record the GPS speed of the vessel to correct for the effect of lateral drift in fall rate calculations. Fall rates were observed in two ways: 1) by measuring the time elapsed between the submersion of two marks (typically 25 or 50 m apart) on the line as it was paid out, and 2) noting the total time and length of line paid out for the cast (Fig. 10).

For the 2013 feasibility study, observed fall speeds indicate that Eric did a poor job of properly weighting the net. On average, the net free-fell at 0.785 ± 0.206 m/s (n=25, CV=26.18%), which is very close to the recommended speed for vertical tows outlined by UNESCO Working Party No. 2 (0.75 m/s, Tranter & Smith 1968) and the fall rate used for plummet tows in Hovekamp (1989), but half the recommended fall rate for capturing euphausiids (Heron 1982). This almost certainly contributed to our poor capture rate of adult krill. Before the 2014 season arrives, the net will be weighted and tested such that a fall rate of 1.25 – 1.5 m/s is consistently achieved.

Our observations also suggested that fall rate vary slightly between less saline shallow (<75m) and deeper, more saline sections of the water column (down to 250m); mean fall rates calculated from shallow-water observations (mean=.844 ± 156 m/s, CV= 18.53%) differ significantly (Student’s t-test, df=37.177,p=.035) from
those calculated for the deeper section (measured from the ~75m time mark to the end of the pay out
(mean=7.02 ± 0.286 m/s, CV=40.8%).

The net is equipped with a flowmeter in order to determine the actual volume of water sampled during each tow. This flowmeter was calibrated in San Diego according to the protocols of the Scripps Pelagic Invertebrate Collection (SIO PIC). The cinching of the net upon retrieval should halt flowmeter spin. Sample volumes calculated from the flowmeter can be checked against expected values given messenger rope payout and drop duration.

The 250 meters of line for these tows are stuffed into a converted recycling bin lashed to the stern rail of the vessel; this ensures the line does not foul during pay-out. The line is marked and color-coded every 25m with permanent marker, and fed through a block suspended from a 72” stainless steel deck crane for obstruction-free pay-out over the stern. A fishing pot line hauler (Ace Brutus, rated to 100 pounds) is used to haul up the net. When the net is retrieved, the mouth ring is hung from a caribener on the crane so that the crew can work on the cod-end without bearing the weight of the net.

Night Sampling
In addition to systematic daytime sampling, six replicate tows will occur at stations in the center of the study area as close to midnight as possible. This area was chosen for its central location, its protection on all sides from weather, its options for anchorage and the fact that both fin and humpback whales focus foraging efforts there. At each night station a plummet tow will be conducted. In addition a light will be suspended near-surface alongside the boat while at the station. This will attract certain micronekton that we can collect opportunistically with a long-arm pool skimmer (333 mirometer mesh).

Preservation

It is important that each tow is rinsed and flushed with thorough and consistent diligence. An advantage of the Heron-Bangarang design is that the net's contents are washed toward the cod-end as it is pulled up. Once out of the water, the cod-end is dunked in the water 4 times to wash contents down further into the bucket. Once on deck, the three sections of the net at the cod end are each washed with one thorough rinse from the seawater hose. This hose is powered by a manual bilge pump fastened to the transom rail. The pump draws water up from a weighted tube dangling below the swimbridge. When not in use, the on-deck hose is coiled around the stern rail and the dangling tube is coiled and stored in a rack on the stern rail.

Samples are preserved immediately in a buffered 5% formaldehyde-seawater solution with a system modeled after that used by the SIO PIC (For details, see Box 1 below). The preservatives are stored on-deck above the aft cabin, contained in a shallow clear-plastic tote that is secured to the mainsheet traveler. 37% formaldehyde is drawn from a 10-L Nalgene carboy via a length of Tygon tubing connected to a 60mL syringe. The proper dosages for various sample volumes are pre-marked on the syringe, so that the correct amount is consistently and easily drawn from the carboy without exposure to the chemicals. To be cautious, however, rubber Atlas gloves are worn during the preservation process, and the formaldehyde is only transferred above a broad, flat Silicone baking sheet secured inside the "Preservation Station" tote; if a spill occurs, the container is removed and the spilled formaldehyde is funneled into a jug that is disposed of as hazardous waste in the fall. A three-way Luer valve is then used to redirect the drawn-out formaldehyde into the sample bag. Again, no exposure to the chemicals should occur. A separate, pre-marked syringe is then used to draw the correct volume of supersaturated borate solution and deposit it into the sample bag, to buffer the sample.

Samples are stored in 27oz. Whirl-Pak bags, which are ideal for our circumstances because they are shatterproof, economical and space-efficient when not yet used. Before each circuit, we mark 20- and 25-oz. fill lines on 35 bags, then double-bag them for added security. An inner label of archival paper and an outer adhesive label is then applied to each sample bag, with the same data written. The rocking of the boat helps to "turn" the preserved samples throughout the day.

3 Ideally, duplicate tows at the Whale Point, Fawcett Point, and north Campania stations.
Box 1. Preservation Station

A shallow rectangular plastic tote is secured to the mainsheet traveler on the topsides of the aft cabin. Holes are drilled into the lowest side of the tote, so that rainwater and condensation drain out. In the tote is a 10-L Nalgene carboy with handles, containing 37% formaldehyde from Dynamic Aqua supply of Vancouver and lashed thoroughly to the deck. The carboy is equipped with a Nalgene 838 lid with two nozzles that can quickly be sealed shut with a spring-loaded release. Only one nozzle is in use; under the cap, a length of Tygon tubing leads to the bottom of the carboy. On the outside of the lid's, a length of tubing leads to a 3-way Luer valve zip-tied to the inside of the tote. On the opposite side of this valve, a length of tubing leads to a 60mL Formaldehyde syringe secured to the inside of the tote. Two lines are marked on this syringe using electrical tape (sharpie faded quickly in the sun). The third end of the valve has tubing leading to a flexible silicon baking pan in the floor of the tote. This tubing is inserted into the Whirl Pak bag and the syringe and valve are used to direct the proper dose of formaldehyde into the bag.

Secured with Velcro to the inside of the tote is another 60 mL syringe reserved for transferring super saturated borate from its jar (also in the preservation tote, secured with Velcro to the floor) to the Whirl Pak sample. The super saturated borate solution (Alta Aecor Sodium tetraborate decahydrate 99+) is from the UCSD chemistry supply department.

A 16-oz squirt bottle, containing filtered seawater, is also Velcro’d to the bottom of the preservation station. Preservation is expedited using a draining sock with 248-micron mesh, loaned from SIO PIC in 2013. A caribiner provides a quick-and-easy way of securing the draining sock to the side of the preservation station during research hours.

Components of the Bangarang Preservation Station. From top, rotating counterclockwise: (i) quick-release cod-end of the net; (ii) a hose, powered by a manual bilge pump, that is filtered through the (iii) plankton sock; (iv) outside and inside archival labels are placed on a (v) double-bagged 27 oz. Whirl-Pak; (vi) a three-way Luer valve toggle directs 37% Formaldehyde to be sucked by a (vii) 60 mL syringe out of a (viii) 10L Nalgene carboy; (ix) another 60mL syringe is then used to deposit the proper dosage of super-saturated Borate into the Whirl Pak. The hose and plankton sock are then used to fill the Whirl-Pak to the appropriate mark with filtered seawater.

Preservation Solution Calculations

A 5% formaldehyde-seawater solution requires 1.5625 mL of 37% Formaldehyde per total fluid ounce of solution, a mixture derived from the convention of adding 50mL of 37% formaldehyde and 20mL of supersaturated buffer per quart of preserved sample (Linsey Sala, pers. comm. 2013).

There are 32 ounces in a quart. If V is the desired volume (in fl ounces) of preserved sample, and F and B are the mL of Formaldehyde and supersaturated Borate solution, respectively, to add to the solution,

\[
\begin{align*}
F/V &= 50 \text{ mL} / 32 \text{ oz.} \\
B/V &= 20 \text{ mL} / 32 \text{ oz.}
\end{align*}
\]

Re-arrange this:

\[
\begin{align*}
F &= 50V / 32 \\
B &= 20V / 32 \text{ oz.}
\end{align*}
\]

For a 25 oz solution of buffered 5% formaldehyde-seawater solution, add 39.1mL of 37% formaldehyde and 15.625 mL of supersaturated Borate. For a 20 oz solution, add 31.3 mL of 37% formaldehyde-seawater and 12.5 mL of super-saturated borate solution.

Preparation

Samples will split by taxon and transferred to small jars (Euphausiid, Copepod, Other) while in the field. As they are separated by taxon individuals are counted and recorded in a home-made data entry program. In the field euphausiids are identified to species, life stage, and measured. Jarred samples are stored in a cooler in the forward head until they are analyzed further in the fall, at which point zooplankton other than euphausiids and copepods will be identified to species. If a collaborator is found, copepods will be counted and identified to at least the genus level. All three taxon jars will be measured for wet biomass.
Transect Design

While underway between stations, we conduct full-effort transects to assess the density of predators and their prey. Designing transect surveys in complex coastal habitats is notoriously difficult (Dawson et al. 2008, Thomas et al. 2007), be it for hydroacoustics, distance sampling, or strip-width sampling. Designing to accommodate all three is a special challenge, but our objectives demand it: we want to investigate the relative predator density found within the prey fields of each study block and test how the spacing of predators and prey differs among blocks and throughout the season. A secondary objective is using these visual surveys to infer local predator population sizes for the study area as a whole. Achieving the former is paramount, achieving the latter as well would be great.

Layout

According to Thomas et al. (2007), a good design…

- employs randomization in laying out transects
- is stratified if density is known to vary on a large scale
- ensures that each location within a stratum has equal coverage probability
- evenly distributes transects (systematic random design)
- contains 10-20 transects per stratum (if strata are used)
- provides for maximum efficiency per unit effort (minimizing off effort time)

Transect lines must represent a sufficiently random sample of all habitat in the study area (Dawson et al. 2008). For the Bangarang Project, however, practical considerations must inform design as long as the known or suspected distribution of the study’s target(s) plays no part (Dawson et al. 2008). In our study, both station and transects were positioned with the practicalities of swell, wind patterns, and viable anchorages in mind. In simulation studies, truly random line placement has no consistent or clear advantage over pseudo-random placement in reducing bias (DuFresne, Fletcher and Dawson 2006). I believe the layout still performs as a design-based approach: properties of the transect layout will be used to make inferences about the populations in question (Thomas et al. 2007).

I chose an near-equally spaced zig-zag configuration for most of our study area, because such layouts tend to make the most efficient use of boat time on the water. Such designs are used in surveys for seabirds (e.g., Becker and Beissinger 1997), cetaceans (Dawson et al. 2008) and forage fish (Simmonds & MacLennan 2005). Zig-zag designs also tend to produce density estimates with low variance (Strindberg 2001). Our transect lines were spaced randomly with respect to known cetacean and seabird hotspots (after Thomas et al. 2007), but were coerced to pass through stations while also yielding transect lengths that provided roughly the same intensity of effort (IE) in each block (equal effort per unit area, after Dawson 2008; see below). However, due to the highly irregular coastline within our study area, we occasionally had to employ “adjusted-angle” techniques (after Thomas et al. 2007). To maximize near-shore sampling we chose to allow our transect zigzags to rebound at the coast (as opposed to the broken-transect designs used in Dawson et al. 2008). There are articles that advise against this design (e.g., Dawson et al. 2008), but there are others that found that connected zig-zag legs can be treated as independent samples without problems (Thomas et al. 2007). The transects have random start points inasmuch as they begin at a station, which was placed randomly with respect to biogeography (including whales).

It is also important for transect lines to be lain across expected gradients in density or environmental variables (O’Driscoll 1998). In fjords, gradients come at you from all sides but the most influential are likely the overall inshore-offshore gradient and the local shore-to-center gradients within channels. I have attempted to design with both gradients in mind here.
Replication & Length

Replication (i.e. multiple discrete transects through the same habitat in the same conditions) is a key to distance sampling analyses (Buckland et al. 2001). Thomas et al. (2007) would not consider their design to be good with less than 15 transects in each stratum. Buckland et al. (2001) recommend 10-20. There are many natural breaking points in our design to provide for this -- stops at stations, observer rotations, etc. Collected data can also be broken up retroactively into more, smaller transects if the need arises.

Defining a transect as a period of full survey effort during which observer positions and vessel heading do not change, our blocks were surveyed using 15-20 transects each. Their mean length (n=71) is 2.79 ± 1.22 km (median=2.7 km, min=0.865 km, max=6.244 km; Fig. 13a). Such lengths yield a mean of 43.98 ± 10.11 km of transect effort within each block and 351.85 km of transects per circuit (table below). There is considerable variation in mean transect length among blocks, which is a result of attempting to keep both intensity of effort and the number of transects relatively consistent within the confines of pragmatism. Adapting the definition from Dawson et al. (2008), I define intensity of effort (IE) as the area scanned as a fraction of the block's total area, i.e., total transect distance (T) multiplied by the strip width (s), divided by the area of the block (A) and expressed as a percentage.

\[
IE = \frac{T \cdot s}{A} \cdot 100
\]

With our current study design, mean IE is 9.11% ± 2% (Table 3). This variation in IE among blocks will be accounted for in analyses of transect results.

### Table. Summary statistics for all eight blocks in the study area and the search effort therein. See text for definition of Intensity of Effort (IE).

<table>
<thead>
<tr>
<th>Block Facts</th>
<th>Area (km²)</th>
<th>Transect Distance (km)</th>
<th>Intensity of Effort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1218.47</td>
<td>351.85</td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>152.31 ± 49.62</td>
<td>43.98 ± 10.11</td>
<td>09.1 ± 01.9</td>
</tr>
<tr>
<td>Median</td>
<td>143.95</td>
<td>42.05</td>
<td>09.4</td>
</tr>
<tr>
<td>CV</td>
<td>32.58%</td>
<td>22.99%</td>
<td>21.88%</td>
</tr>
<tr>
<td>Minimum</td>
<td>87.71</td>
<td>34.76</td>
<td>06.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>226.16</td>
<td>66.02</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Assessing Bias

My layout design possibly introduces bias to my abundance estimates. If I have time I will conduct simulations to assess this bias and where in the circuit it is most severe.

Distance Methods

Line transect methods can be used to estimate absolute abundances of populations, and are common in cetacean surveys (Kinsey et al. 2000). Unlike strip-width sampling (see below), which limits the area you search and assumes that you see everything in that confined search area, distance sampling requires that you record
all sightings, regardless of distance, but that you also record the distance of each sighting from your trackline. This is done using some range finding technique. A curve (known as a “detection function”) is then fitted to those detection distances in order to estimate the probability of seeing a certain species at a certain distance. Survey results can then be adjusted according to these probabilities to produce unbiased density estimates for an area. 60-80 sightings are recommended to acquire a good fit to such detection functions (Buckland et al. 2001), and 20-30 sightings should be considered a minimum. This sample size was achieved in 2013 for both humpback and fin whales, but the detection functions will be even more tightly constrained after 3 seasons of fieldwork.

We conducted distance sampling according to the methodologies outlined in Buckland et al. (2001 and 2004). Line transect analyses require the following data to be collected: 1) the angle between the track line and the sighting, and 2) the shortest straight-line, or radial, distance to the sighting (Kinzey et al. 2000). We record a compass bearing and binocular reticle to every whale and vessel we see, as well as the vessel heading, so that we can produce a precise map of their distribution (when first seen) for every block and ultimately produce absolute abundance estimates. Certain small bays within our study area, such as Bishop Bay in Ursula Channel (Fig. 1), were able to be so thoroughly surveyed that they may be treated as “census areas” for certain species – where all animals would be completely counted as we pass (after Thomas et al. 2007).

Distances are estimated using Fujinon FMTRC-SX 7x50 binoculars, which display reticles and a compass bearing in the left eyepiece. These same 7x50 binoculars were used by all observers on SWFSC harbor porpoise surveys and by the data recorder on surveys for larger cetaceans (Kinzey et al. 2000). The binoculars’ compass is graduated in 1-degree increments (Kinzey et al. 2000). One eyepiece has reticles of alternating broad and skinny width, but we treated the distance between every line as a full reticle (after Kinzey & Gerrodette 2001). A conversion factor of 0.279 degrees/reticle, which has been determined empirically for this type of binocular by Kinzey & Gerrodette (2001), is used to determine the angle between the observer’s vantage of the horizon or shore to her vantage of the sighting (Fig. 17). This angle is then incorporated into the equations outlined in Lerzak & Hobbs (1998) to determine the distance over the earth’s (assumed) spherical surface to the sighting (Fig. 18). These equations also require the observer’s height above water, which is measured for all crew at all positions. Observer name, position, and their reticle and bearing reading is recorded for every sighting during transect effort.

**Fixed-width Methods**

To count seabirds, pinnipeds, jumping fish and debris we use a fixed-width survey design (after RIC 1995, Hamer 1997, RIC 2001 and many others). Patches of kelp, wood, trash, surface plankton (e.g., jellies or red tide belts), and dead animals are counted using the same strip width.

**Strip Width**

A critical requirement of a strip-width survey is that 100% of events within the strip must be observed and noted; to ensure that all birds within the strip are seen. A standard fixed-width for seabird surveys is 300m (Tasker et al. 1984; Gould & Forsell 1989, Russell et al. 1992, Fauchald & Erikstad 2002, Logerwell & Hargreaves 1996), often on the non-glare side of the vessel. While some surveys (e.g., Mahon et al. 1992) have used 500m strip-widths for marbled murrelets surveys, it is know know that alcids and other inconspicuous seabirds are not reliably censused from a vessel beyond 150-175m – especially a small, low-platform vessel (Dixon 1977, Briggs and Hunt 1981, Wiens et al. 1978, Tasker et al. 1984, Briggs et al. 1985a). Ralph et al. (1990) suggests detectability for marbled murrelets may drop off beyond just 100m. A further consideration is that we are investigating spatial patterns between seabirds and the acoustic backscatter from our hydroacoustic surveys (which is downscanning the water column on both sides of the ship equally), and we’d like to maximize their overlap to the extent possible (to this end Piatt (1990) used only a 50m radius on each side of the boat).

Because pinnipeds and mustelids are inconspicuous in water and inconsistently at sea, distance sampling is not a reliable method for pinniped abundance estimation (Chapman et al. 2004). Aerial and land-based surveys of haul-out sites are typically used (Loughlin et al. 1992, Bengston et al. 2005). However, the pelagic distribution of British Columbia pinnipeds is a recognized knowledge gap (Williams & Thomas 2007) and such data are needed to ascertain associations with the environment, prey and competitors. To achieve the latter Ribic et al. (1991) used strip-width methodology (300m to one side of the vessel) for pinniped surveys from a large vessel.
(10m+ platform height). Other studies have surveyed at-sea pinniped distribution similarly (Ballance 2010). A fixed-width method with the 300m strip centered over the vessel should allow us to study pinniped spatial association and relative densities at-sea while simultaneously assessing biases due to avoidance and sightability.

Ronconi and Burger (2009) recommend that surveyors develop independent estimates of detection probability alongside a strip-width survey to test the assumptions of this transect methodology. A detection function can also be used to determine empirically the actual strip width within which you see 100% of target species occurrences -- rather than assuming its width (Buckland et al. 2001, Dawson et al. 2008). In my study I am trialing a different method of assessing transect performance: a split strip-width design.

On the Bangarang, we maintain a 300m strip-width but place ourselves in the center of the strip and record sightings on 150m of both sides of the vessel (as recommended in RIC 1997, Burger and Lawrence 1995, Van Franeker 1994). Further, we divide each side of the vessel into two strips: from the vessel to 50m and from 50m to 150m (similar to recommendations in RIC 2001). Handheld rangefinders are used to determine which strip each sighting falls into. In effect we are reporting on densities within 4 fixed-strips at once. This design will allow me to check for species-specific effects of avoidance and reduced strip widths for inconspicuous species. In the event that this split fixed-width method is overwhelming in areas of high density, the observer team can switch to simple 300m strip-width methodology and the change in effort will be duly noted.

**Range Finder**

In order to know whether or not a bird is within the 50m or 150m strip, Bangarang observers use a handheld range finder that is customized to their own height and arm length. Handheld, home-made range finders have been used for offshore seabird surveys with unobstructed horizons (Heinemann 1981; Ballance 2010), but no solution has been offered, to my knowledge, for coastal studies where the horizon is obstructed by land. Because this study occurs predominantly within confined channels, our range finders are referenced not to the horizon, but to an imaginary horizontal line extending from the observers eyes to the topside of the range finder (Box 2). A level bubble on the range finder indicates when the range finder itself is held vertically. The broad topside of the range finder, when held at the same level of the eye, will not be visible. When both conditions are met, a properly drawn line on the range finder will demarcate viewing areas with radii of 50m and 150m for that specific observer. For example, everything below and closer than the 50m line is within the narrow strip; everything above and beyond the 150m line is outside of the strip and is not noted unless it is particularly noteworthy. Because there is inevitably some error in this method, sightings that occur very close to the strip boundaries are noted as such in the data entry program. In 2013 buoys towed 150m behind the vessel to test the performance of these rangefinder. Results were surprisingly accurate.

**Figure.** a) The Bangarang handheld rangefinder, referenced to a horizontal plane. The trigonometry involved in designing such a rangefinder is demonstrated here. b) A first-person point-of-view of how the handheld range finder is used. The alcid is within the strip; the closest shore is just outside of the strip.
Box 2. Range Finder Calculations

The distance (in cm), \( r \), of the 150m strip mark from the top of the range finder can be calculated as

\[
r = \left( \frac{d}{2} \right) (h + b)
\]

Where
- \( d \) = distance from crew’s eyes to the range finder
- \( h \) = height of crew’s eyes above boat deck
- \( b \) = height of boat deck above water
- \( D \) = strip width (in our case, 150m)

This equation does not account for the curvature of the earth. For each observer, the height of their eyes above water changes for each observer position, meaning Bangarang range finders have three marks, each corresponding to a different position. The three heights we had to calculate for were...

i) Helm (the height from the waterline of the data laptop stand): 142.24 cm
ii) Bow (height from waterline to the deck at the base of the staysail shroud): 108.00 cm
iii) Mid-ship sitting position (height from water to upper deck topsides abaft of the mast: 153.98 cm

For each observer, the following measurements are taken to craft his or her rangefinder:

a) Standing eye height (with boots on).

b) Height of eyes above the data laptop stand when sitting erect at the helm.

c) Arm length from the edge of the range finder facing the chest to the back of the eye, with shoulders square.

Using these same measurements, repeat the calculation for the 50m strip mark.

Seabird Issues

Seabird strip-width methodology is modeled after Tasker et al. (1984), Raphael et al. (2007), RIC (1997), and Ballance (2010), among others. During transects and when sighting a bird, we record all factors affecting its visibility (flock size, behavior, sea state, weather conditions, glare angle, vessel speed and heading, observer, etc.; after RIC 1997, Tasker et al. 1984).

Continuous Counting: I am interested first in seabird habitat choices based on strategies for acquiring prey, but to the extent possible would like to estimate species abundances within my study area. As such I wanted seabird counts to address fine scale spatial patterns (after RIC 1997 and Spear et al. 1992, based upon reviews in Schneider and Duffy 1985, Schneider and Piatt 1986, Haney and Solow 1992; as achieved in O’Driscoll 1998). To achieve this, we recorded seabird observations continuously, opting not to perform snapshot counts at intervals (after Russell et al. 1992, Fauchald et al. 2000). The 2013 season demonstrated that densities allowed for this continuous sampling without experiencing overload. We were also able to count flying birds without missing stationary birds, so we counted them all. Data can be pooled into time bins later (and flying birds removed) if necessary.

Birds in Flight: Continuous counts of flying birds run the risk of “overestimation of birds caused by flux” (Tasker et al. 1984) and it is essential to note whether birds are on the water or in flight (RIC 1997). This gives researchers the options of including only sitting birds in analyses (after Russell et al. 1992, Fauchald & Erikstad 2002, Fauchald et al. 2000, Piatt 1990) or comparing results from on- and off-water birds (after O’Driscoll 1998) to get a sense of foraging preferences. Birds in flight are often assumed to be unassociated with underlying prey because they are commuting between foraging areas (Russell et al. 1992), but this is not always the case. During flight seabirds are assessing prey fields and making foraging decisions (Gaston 2004) and birds on the water have not necessarily landed to feed (Grover & Olla 1983).

It is possible that overestimation due to flux can be accounted for if the appropriate data are collected (i.e., behavior, direction of travel if in flight, and wind speed and direction; RIC 1997, Spears and Ainley 1997). To counter overestimation, Spear et al. (1992) re-sighted birds, taking their bearing and distance from the boat a second time-- as well as the time between position fixes and the geospatial position, heading, and speed of the vessel at each fix. This proved infeasible for our platform and purposes. Instead the Bangarang Project follows the lead of Spear and Ainley (1997), supplemented by Schnell & Hellack (1979), Pennycuick (1982, 1987) and Alerstam et al. (1993). In each sighting, we record bird direction of flight, height over water, and wind speed and
Readings of wind speed and direction are taken at 1-minute intervals by 5m-high weather station\(^4\). These wind readings can then be scaled to the bird’s altitude using published correction factors (Pennycuick 1982). We will group our seabirds into the same categories as Spear and Ainley (1997) according to wing loading, flight style and known effect of wind direction on flight speed. We can then use Spear and Ainley’s (1997) published flight speeds of each group in various orientations to the wind to account for bird flux in our density estimations.

**Acoustic Transects**

**Active**

The Bangarang Project will hopefully contribute to a body of peer-reviewed work that uses low-cost echosounders for studies of cetacean foraging strategy (e.g., MacLennon & Simmons 1992; Dolphin 1987, 1988; Piatt 1987, 1990; Piatt et al. 1989; Burger & Piatt 1990; Piatt & Methven 1992; O’Driscoll 1998; Benoit-Bird et al. 2001; Benoit-Bird & Au 2003). On the Bangarang I use a downsounding dual-beam (33kHz and 200kHz) Syqwest Hydrobox. The Hydrobox transmits at 600 Watts. The low frequency pings (33kHz, up 10 Hz ping rate, 45 dB gain 18 degree beam width) reflect schooling fish down to 600m. The high frequency pings (200kHz, up 10 Hz ping rate, 75 dB gain, 10 degree beam width) generate fish and zooplankton backscatter at .01m-resolution down to 250m, the same depth as our tows. In some ways my echosounder, the Syqwest Hydrobox, is more “scientific” than the instruments used in the above studies in that 1) power output is not variable and Time-Varied Gain (TVG) is used in processing returned echo strengths, 2) sensitivity and depth range parameters can be manually chosen and locked, and 3) each ping of echo data is output (with some processing) as a NMEA string with GPS-stamps, time-stamps and calculated vessel heading and speed.

Each NMEA string contains 200 pixel values representing 2.5m vertical bins of echo-integrated backscatter from 0-500m depth (processed in the sensor using a detection threshold of “0” and sound speed of 1490 m/s). These strings are saved in a single playback file, from which pixel data can be extracted using a binary editor in post-hoc processing. To investigate the possibility of roughly calibrating the unit for more quantitative analyses, I conducted calibration measurements using a Tungsten-Carbine sphere dangled 10m below the transducer in 2013. The transducer is deployed from the port transom, suspended from a stainless steel pipe that secured to the vessel’s swimbridge. When not in use the transducer swings up on a hinge for safe stowage. The transducer’s signal is passed via a long weather-proof cable to the acoustics station at the cabin’s dinette. A dedicated active acoustics laptop records the echosounder data for real-time display as well as analysis and review in the off-season. The echosounder is powered by the ship’s research battery to eliminate electrical interference.

In R, echograms will be produced for visualization, quality control and exploratory analysis\(^5\). Visual survey data (effort, conditions and sightings) will be attributed to coincident pings using time-stamp matching. Because vessel speed can be variable while with whales, the 0.5 Hz pings for each frequency will be averaged into 10m (.0001 decimal degree) bins.

**Passive**

An oil-filled hydrophone array is towed 100m behind the vessel during transects. When not in use it is stored on

\(^4\) In 2013, we only had our handheld Kestrel 2000, which we used for wind readings at stations.

\(^5\) Pixel data below 2.5m above the seafloor depth and 2.5m below the surface will be removed along with periods of self-noise or any other malfunctions. Because the high frequency backscatter begins to drop out below 250m, all pixel data below 200m (to be conservative) will be removed. Since I run the exact same transect lines repeatedly throughout a season and between seasons, I can use the pixel intensity of the reflected seafloor to check for drift over time in the echosounder’s output and/or processor.
deck on a spooling Reel-Core 24” diameter plastic reel. The spool allows us to perform tangle-free pay out and retrieval of the 100m of cable in less than two minutes. The mount is constructed of pressure-treated wood, twice-varnished and secured to the mainsheet traveler of the vessel.

The array itself consists of 2 HTI-96MIN hydrophones with 10Hz high pass and built-in pre-amps positioned 3 meters apart. I added a pre-amplifier in the array that provides 20dB gain to both signals and a soft 480 Hz high pass. The array is also equipped with a depth sensor. These hydrophones are powered by the vessel's 12V AGM research battery, which is isolated via switches from engine and house electronics. When the hydrophone and echosounder are not in use, the research battery is charged by the engine’s alternator. The hydrophone was also constructed such that a 9V battery can be used as a stand-in if needed.

The signal is fed into the cabin to the dinette acoustic station (Fig. 16b), where sounds are recorded directly onto a laptop using Cornell's software Raven. Recordings use a 2-channel, 32 kHz sampling rate. If conditions allow, the hydrophone remains deployed at stations (for convenience), but problems arose in 2013 when a standing wave in Verney Passage caused the hydrophone cable to knot up and malfunction.

An energy-efficient 19” LG E2050-T LCD monitor is installed in the salon bulkhead. It is viewable to the helmsman during transects and displays a live spectrogram of incoming recordings at both mid (0.1-16 kHz) and infrasonic (0-100Hz) frequencies in Raven. The mid-frequency spectrogram uses a Hann window (1050 samples with a 60.4 Hz 3dB Filter Bandwidth), 50% overlap, 525-sample hopsize, and DFT size of 2048 samples. The infrasonic spectrogram uses a Hann window (15586 samples, 4.07 Hz 3dB filter bandwidth), 50% overlap, 7793-sample hop size, and DFT of 16584 samples.

Three additional acoustic recording packages are onboard: a back-up, hand-deployable towed array built from a Navy-surplus Sonobuoy; an over-the-side back-up; and a drifting recorder that can be deployed in the vicinity of whales and collected after close-approaches are complete. With these four instruments, a high percentage of fin whale sightings will have an associated recording.
Transect Effort

During the day, survey data are collected in one of two modes: 1) on-transect searching and 2) “with-whales” closing (after Kinzey et al. 2000).

Vessel speed

The S.V. Bangarang is not known for its speed. Reasons for our slow pace include the hull speed of the vessel (6.5 knots), the fact that the echosounder and hydrophone begin to generate self-noise at high engine RPM (>1500), and the fact that lower speeds allow us to perform four surveys simultaneously – two acoustic and two visual. Due to the great variability in the strength and direction of tidal currents within the area, we endeavor to maintain a transit speed between 4 and 5.5 knots at 1500 RPM, but must prioritize constant engine speed for the sake of acoustic data. Published, peer-reviewed seabird studies have been produced from surveys at 6 knots or below (Brown et al. 1975, Powers et al. 1980, Tasker et al. 1984, Logerwell & Hargreaves 1996, O’Driscoll 1998). Speeds below 8 knots are atypically slow for cetacean distance sampling surveys. According to convention, survey speed should be at least 2-3 times faster than the typical average speed of the animals (Hiby 1982). We can achieve this for the average milling humpback whale, but not for any species in the act of directed travel. However, the confined waterways of our study area make it easy to track sightings, predict their movement, and avoid recounting.

The “RU: Bangarang” data entry program logs vessel position every 15 seconds. An external antenna is mounted 5m high and clear of obstructions for increased position accuracy. The echosounder logs position, heading, speed and direction every one second. A handheld GPS device is also on board and is recording vessel tracks as a back up. The vessel can deviate by up to 20 degrees from the planned trackline to avoid swell, glare or rain squalls, returning to the original course once conditions have improved. Course deviations from the trackline while in on-effort mode in order to examine “interesting” areas such as floating debris that may attract cetaceans or other fauna are prohibited. Once such areas are past 90 degrees abeam the observers may elect to enter “off effort” mode, double back and explore the area.

Time of Day

The optimal dates and times for sampling differs among the species I am targeting in my surveys (RIC 1997). Planktivorous seabirds are often most active at dusk and dawn and may not be associated with prey schools during the day (RIC 1997). The marbled murrelet is an example of a primarily piscivorous species with strong diurnal signature in their behavior and distribution (RIC 2001). Marbled murrelets are unique among North American seabirds in that they nest in old growth conifers (Nelson1997), to and from which they fly every dawn and dusk. As a result marbled murrelets are found directly offshore of nesting flyways at dawn (Ralph et al. 1995). To complicate matters further, daily activity patterns vary throughout the breeding season and among different locations (Hooper 2001, Derocher et al. 1996, Carter 1984). But the marbled murrelet is listed as Threatened by COSEWIC and red-listed in British Columbia. Inventorying its at-sea density and habitat use could be an important contribution of the Bangarang project.

I am interested first in seabird habitat choices based on strategies for acquiring prey but to the extent possible would like to estimate species abundances within my study area. Diurnal sampling should reflect seabird habitat choices based on foraging strategies for most species. The key to successfully sampling this diverse community is diurnal consistency in effort (RIC 1997, Fauchald et al. 2000). The Bangarang begins transect effort each day between 30 minutes and 1 hour after dawn (after recommendations for marbled murrelet inventory methods: Becker & Beissinger 1997, RIC 2001).

Meteorology

Climate conditions are logged every minute with an AccuVue wireless weather station mounted 5m above the water. The station logs temperature, wind strength and direction, barometric pressure and other variables.
These measurements are sent wireless to the data laptop and are later synchronized to effort and sightings data. Sighting conditions are recorded at each station, as well as whenever any of them markedly change between stations: sea state using the Beaufort scale (Table 1); swell height, using binned height categories; estimated percent cloud cover; visibility, using binned distance categories; precipitation status; the bearing of the left and right extent of glare, if any; tidal current strength (weak, moderate, or strong) and direction; and engine RPM (the ratio of vessel speed to RPM can be used to assess windage and water current speed).

<table>
<thead>
<tr>
<th>Wind Force (Beaufort)</th>
<th>Knots</th>
<th>Breeze description</th>
<th>Sea conditions</th>
<th>Probable wave height (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-1</td>
<td>Calm</td>
<td>Sea smooth and mirror-like</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1-3</td>
<td>Light air</td>
<td>Scale-like ripple without foam crests</td>
<td>1/4</td>
</tr>
<tr>
<td>2</td>
<td>4-6</td>
<td>Light breeze</td>
<td>Small short waves; crests have a glassy appearance and do not break</td>
<td>1/2</td>
</tr>
<tr>
<td>3</td>
<td>7-10</td>
<td>Gentle breeze</td>
<td>Large waves; some crests begin to break; foam of glassy appearance. Occasional white foam crests</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>11-16</td>
<td>Moderate breeze</td>
<td>Small waves, becoming longer; rarely frequent white foam crests</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>17-21</td>
<td>Fresh breeze</td>
<td>Moderate waves, taking a more pronounced long form; many white foam crests; there may be some spray</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>22-27</td>
<td>Strong breeze</td>
<td>Large waves begin to form; white foam crests and more extensive everywhere; there may be some spray</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. Sea state conditions: the Beaufort scale (from Bowditch 1966)

Observer Positions

Seabird methodology papers concur that at least two observers are needed to adequately survey a strip of 300m (Raphael et al. 2007, Tasker et al. 1984, Becker & Beissinger YEAR, RIC 1997, Spear et al. 2004). To adequately cover this 300-m wide viewshed on the Bangarang, one observer is positioned at the bow and is responsible for surveying one side of the boat, from 10% beyond dead ahead to 90 degrees abeam. Another observer is placed at midships on the other side of the boat; she and the helmsman are responsible for surveying the other side of the boat (Fig. 20). Since the midships observer is responsible for relaying sightings to the helmsman, who is also navigating and entering data, their two efforts combine to ensure that all possible sightings on their side are recorded. Halfway between stations, the two "observer teams" switch sides, so that if there is observer bias it is reduced and observable (Piatt 1990). All position changes are noted in the data entry program. To prevent fatigue, observer positions are rotated frequently (average of every 2.75km or 15 minutes). Station work provides an opportunity for rest and recuperation. In 2013, the day was found to be so diverse given transect, station and with-whales work that fatigue was generally not an issue. However, the use of a partitioned survey strip (0-50 and 50-150m) will allow me to reduce the sightings used in analysis if fatigue (or sighting conditions) are thought to be a factor for certain transects.

Eye heights of 4.5 to 6m are typical of published small boat distance sampling surveys (Dawson et al. 2008). Average eye height for observers on the Bangarang, depending on their position and height, ranged from 2.75 to 3.75 m. Although sighting platforms are recommended (Dawson et al. 2008), we did not have the financial means of installing such a platform on the Bangarang in 2013. Given the general low sea state and the reduced visual range in the study area’s confined channels, we pressed onward. A sighting platform will be added in 2014 if funds become available.

Observer Training

When new observers come on board, they are immediately measured and a range finder is built for them.

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6 In 2013, we used a handheld Kestrel 2000 for meteorological readings.
Becoming adroit at field identification of the local marine mammal species is a quick process, and seasoned observers help new crew learn the ropes. The most difficult aspect of joining the observer team is seabird identification. Experience with Pacific Northwest birds is highly encouraged among candidate observers, and at minimum we require observers to be experienced birders. A list of local seabirds is given to each observer before the season, and concise Bangarang-made field identification keys are also at their disposal before they come on board. Several published guides are available to them in the onboard library. Before a new circuit is begun with the new observer(s), several days are spent working on seabird identification, during which the observers also calibrate their sense of strip width, practice range finding, and familiarize with best practices in distance sampling (see below). A fender is tied to the zooplankton tow line and paid out 150m while the boat is underway (after RIC 1997), so that the observers have a concrete sense of what 150m looks like and how their range finder works. Observers are alert to the problem of following or “leap-frogging” birds, and they are trained to make a conscientious team effort not to re-count followers (such birds are logged as followers in the data entry program).

Eric serves as the ID specialist on board, with final word on difficult sightings. He is on watch at all times, ensuring that surveys are conducted correctly and consistently. He decides when to go on and off effort, and whether to pass or close on a sighting.

Scanning

Observers actively scan the 180 degrees forward of the ship for new sightings (see observer positions below). Only sightings made during this “on-effort” mode are used in the line-transect estimates of abundance, but any and all whale sightings during waking hours are noted in the data entry program and “closed on” whenever possible. Transect effort is terminated once the sea state reaches Beaufort 4, above which inconspicuous seabirds and small cetaceans become very difficult to see (after Ralph and Miller 1994, Raphael et al. 2007, RIC 1997, RIC 2001). For most survey days in 2013 we had BFT sea states 0 to 2, which is best for marbled murrelet surveys (RIC 2001).

Only sightings made by the three designated observers, in the three designated positions, can “count” toward line-transect results. If guests are on board, they may not inform observers of missed sightings, whale or bird or whatever, until after the sighting has passed abeam, whereupon Eric will make the appropriate notes for an off-effort sighting (after Kinzey et al. 2000). These sightings, however, will not be used in line-transect analyses of abundance. It is important, however, to let Eric know of missed whale sightings as soon as possible, because the decision to “close” on a sighting is time-sensitive.

Each observer scans out to the horizon from 90 degrees abeam of her side of the ship to 10 degrees to the opposite side of the bow. Each observer is therefore responsible for 100 degrees in all. This provides emphatic coverage of the 20 degrees along the ship’s trackline by both observers (after Kinzey et al. 2000; Dawson et al. 2008) while lateral regions are each covered by the equivalent of one observer. In addition to scanning one side of the viewshed alongside the midships-man, the helmsman/data recorder enters sightings, weather, navigation, searching effort, observer positions, and other data into the laptop.

Observers scan their entire area of responsibility in a consistent manner and do not focus on particular regions. The principles of distance sampling are presented to observers in a written manual (see Bangarang Bible) prior to surveys, reiterated when they arrive on board, and repeated throughout their stint on the crew. A burn-in period of practice transects are used to introduce best practices to new observers.

Observers are asked to scan primarily without the aid of binoculars. Fujinon 7x50 binoculars are used to identify sightings to species and record bearing/reticle measurements for each sighting but not to locate new birds (RIC 1997, 2001). However, observers may conduct occasional scans with binoculars, especially during midday when lighting conditions are not conducive to distant detections. The details of scanning rates and patterns are left to the individual observer’s preference (after Barlow 1999).

Debris

Any type of surface debris, anthropogenic or natural, is noted if it is found within the strip (after Ballance 2010). We log debris type (e.g., rockweed, log, kelp), extent and associated fauna. Phytoplankton and jelly sightings are also logged.
Fish
Prey fishes breaking the ocean surface are also recorded. In the study area jumping fish are common and are usually salmon. When a salmon is seen, the following information is relayed to the helmsman: number of jumps, who observed the jumps, whether it was within the strip, and whether it was close to the border of the strip. It is the responsibility of each observer not to count the same salmon twice. If it is possible that a jumping salmon could have already been reported, it should not be reported again.

Seabirds
Birds are logged as soon as they are seen within the survey strip. The following information is relayed to the helmsman: species present (and their percent composition of the entire flock), plumage composition for each species, behavior, direction of flight (if flying), elevation of bird (if flying)\(^7\), group size, and observer name. If the bird is outside of the strip width, that must also be communicated; if the bird is close to the strip border, this must be reported as well.

For some species like marbled murrelets, counts of newly fledged juveniles on the water are an important measure of breeding success and productivity, especially mid-June through August in BC (RIC 2001). Plumage composition for each flock is logged for all species. For marbled murrelet plumage classification, what we record as “breeding plumage” corresponds to classes 1-3 in Raphael et al. (2007) (which were based on Strong 1998) and the “alternate plumage” designation in RIC (2001); our “winter plumage” record corresponds to classes 4-7 in the former and “basic plumage” in the latter.

A flock is defined as birds that are less than 2m apart (RIC 2001) who presence is thought to be influencing that of the other (as in Ballance 2010). The behavior of birds that are flushed or dive in reaction to the vessel is noted as “flushed” (RIC 1997). A bird seen as landing or taking off is logged as being on the water, unless flushed (after RIC 1997). Notes are made when any birds are seen holding fish (as in RIC 2001). “Complete” flock counts (accurate identification of all species and the number of individuals per species) can be difficult to obtain. When faced with overwhelming sightings, observers prioritize data collection using the following hierarchy (after Ballance 2010):

1. Obtain a count of total number of individuals.
2. Obtain a general categorization of taxa and numbers for each (for example: small gulls = 50, large gulls = 150, terns = 75);
3. Look for rare species
4. Obtain accurate counts for each taxon.
5. Obtain accurate counts for each species.

If an incomplete count is necessary, the occurrence of the flock is still noted and observers report as far down the above hierarchy as they can. The helmsman enters the data but also notes that the count is incomplete. Group sizes of diving alcids are estimates of the entire group including both on-surface and underwater birds.

When species identification is not possible, sightings are logged as the taxon-level at which there is certainty (after Fauchald et al 2000, Fauchald & Erikstad 2002; i.e., an ambiguous large gull will be classified as W/H/C for Western/Herring/California). Entry forms in the RU: Bangarang data entry program accommodate those broader categories (See RU Bangarang Users Manual). If other observers are onboard they are welcome to aid in species identification and group size counting. Where possible, photographs are taken of large seabird groups for use in retroactive group size corrections (after Gerrodette and Perrin 1991).

Noteworthy sightings (e.g., rare birds) that occur outside of the strip-width are still noted but marked “outside of strip”.

Pinnipeds & mustelids
When sea lions, seals or otters are seen, the following data are entered: strip location, species, group size, behavior and direction of travel, and other notes. The following behaviors are logged: finning, bobbing (vertically, usually just for harbor seals), slow swimming, porpoising, feeding and playing.

Cetaceans

\(^7\) Flying height is reported in binned elevations: surface to eye-level, eye-level to 5m, 5m to mid-mast, mid-mast to top of mast, above mast
A whale sighting is entered when the presence of a marine mammal has been observed at 0.1 reticles or closer. Any further animals will be too difficult to track and are more prone to accidental re-counting. If a sighting beyond 0.1 reticles is seen, it cannot be counted as a sighting until it enters within 0.1 reticles. But these too-far sightings can be entered as a comment at any time.

Observers do not report a cue (e.g., a splash), but wait until it is actually a confirmed sighting. However, the cue behavior is logged in the sightings form because certain behaviors change the likelihood of seeing a whale at a certain distance (e.g., breaches are seen from much farther away than blows). Observers should not neglect the rest of their area by focusing on the region of the cue for more than a minute or so at a time while in searching mode.

For each sighting, the following data are reported to the helmsman: reticle, bearing, the observer (this is whoever is reporting the reticle, not who saw the group first), species, group size (minimum, maximum, and best guess), a general description of its location (to help keep track of various sightings), and the initial behavior of the group (this is typically just “blow”).

Effort is made to locate marine mammals at as great a distance from the research vessel as possible, before they may have altered their position or behavior in response to it. If sightings are well away from us, even if they are near the track line and easily visible, observers must stay in on-effort searching mode. They must not fixate on the open sightings. Rather, they keep scanning the entire area as before. If an extra person is available, her job is to track the school.

**Vessels**

Vessel sightings should not be entered until the *Bangarang* is as close as it will get to the sighted vessel. This will improve our estimate of the vessel’s position. If, however, there are too many vessels to keep track of, or if there is a risk that the vessel will be out of view soon, the vessel is promptly entered as a sighting. It is the responsibility of the observers to collectively keep track of all vessels and marine mammals currently in view, making sure not to recount or let anything fall “through the cracks”. This is especially important when observers rotate positions; the team should brief each other on what is currently in view. It is also the responsibility of the helmsman to pay attention to the sightings data he is entering; if it observers might be accidentally reporting the same sighting, ask the necessary questions to ensure it does not continue. If many sightings are currently open and in view, Eric may decide to forego position rotations so as to track whales as accurately as possible.
Close Approaches

When whales are within a feasible distance to us, we will break transect and take photographs, behavioral notes, and samples. All observations are made from a respectful distance, and sightings are abandoned if the whales react negatively to or avoid the vessel. We strictly adhere to the research etiquette exemplified by the North Coast Cetacean Society.

“Closing”

The decision to break transect and close on a sighting is a complicated one (Dawson et al. 2008). Because our travel speed is slow (maximum 7 knots), breaking transect to go “with whales” then returning to the breaking point can be an hours-long endeavor – especially when chasing energetic fin whales. The tidal current direction, current and forecasted wind speed, amount of station work remaining, and the number of sightings at hand will all contribute to the decision. It is a hard truth that we are unable to pursue every sighting. Often, seen whales are traveling in a direction that will bring them closer to us further on down our transect lines; in such cases, we do not break transect until we are as close as we will get.

When multiple sightings are in view, the nearest on-effort sighting, rather than the earliest seen, is typically approached first. However, this also depends on the species on offer. Generally speaking, fin whales are highest priority, followed by orca (who are second than highest only because they are more easily caught up to), followed by humpbacks.

When Eric makes the decision to leave the transect to approach (or “close”) on a sighting, effort is switched to “casual” until the vessel approaches within 150m of the school. During closing, the observers take out and prepare cameras, and acoustic instruments are parameterized for the encounter. Until the sighting is within range, engine speed can increase beyond the 1500 RPM that is maintained during transects.

“With Whales”

Once we are within 150m of the sighting, our effort is considered to be “with whales”. This is the distance from which every breath can reliably be recorded, individuals within a group can be tracked, school position updates can accurately be given, subsurface behaviors can be inferred, school size can accurately estimated, and adequate photographs can be taken. A radius of 150m around a foraging whale is also a reasonable (even conservative) estimate of the prey field area the animal can “sample” within a single dive. This distance is also easily and accurately determined using the Bangarang range finders. It is essential that this 150m designation be taken seriously; it is possible that, in pursuit of a sighting, we may enter in and out of “with whales” range, and our effort should be noted accordingly. Analyses of echosounder data depend on an accurate record of when we are and are not with foraging whales.

Once “with whales”, engine RPM is kept below 1500 to ensure high quality echo-sounding (and often much lower, to minimize the impact of our presence on the group). Sightings of new schools while already “with whales” are recorded as off-effort sightings. Attention is not focused on these sightings until the current encounter is a success, but other such group(s) are loosely tracked. After finishing data collection for the on-effort sighting, an off-effort sighting may be approached if it is a priority species. If an off-effort school is re-sighted later after returning to search mode, it may be recorded as an on-effort sighting.

When working “with whales”, the following data are collected, usually in this order:

1. Basic data
2. Acoustic prey mapping
3. Respiration intervals
4. Travel patterns
5. Photo-ID
6. Passive acoustics
7. Travel Patterns
8. Sample collection

The generally crew divides responsibilities as follows: the helmsman (almost always Eric) enters data and breath intervals while navigating the vessel; both crew members have cameras at the ready, but one is also range finding the whale and calling out distance and bearing of each surfacing. The other is keeping a general eye out for other whales, vessels, scat or prey remains.

Basic Data

Species Identification
In a close approach, there is never any doubt about which species are present.

Group size
Here we define a group after Clapham (2000) and Notobartolo-di-Sciara et al. (2003), as “affiliations in which two or more individuals swim side by side within 1-2 body lengths and generally coordinate at least their surfacing and diving, as well as their speed and direction of movement.” Determining whether two or more groups are subgroups of the same school or separate schools is difficult. Groups that are definitely not interacting are counted as separate sightings. For the convenience of data entry, a dispersed group consisting of smaller subgroups is counted as a single sighting. Comments are then made to articulate how the group is structured, usually in the syntax “3 + 4 + 2 + 2”, for example. In the “With Whales” entry form, behaviors can be attributed to the entire group or to specified individuals (arbitrarily designated as individual A, B, C, etc.). If it becomes necessary to regard subgroups as distinct groups or sightings, new sighting numbers can be applied post-hoc, when the day’s data are reviewed the evening of. On the Image Processing datasheet (see Bangarang Bible), photographs of individuals are organized into their subgroup associations.

New sightings are assigned only when there is no doubt that the mammal or group of mammals has not already been assigned a number. If there is any doubt, the animals in question are considered part of the already entered sighting.

Species and group size (minimum, maximum, and best guess) are identified by consensus, though Eric has the final word on how a sighting will be entered into RUB. In some circumstances, only a low estimate is possible. To estimate group size, the observers on watch estimate the number of mammals in the school, all taxa combined. If more than one taxon is present, % composition of each sighting category in the school is also estimated by the observer team. For large cetacean schools or bird flocks, photographs are taken where possible. These can be used to more accurately estimate group size and aid in calibrating new observers on group size estimation.

Behavior Assignment - Humpbacks
Some behaviors are explicit and easily recorded, such as “blow”, “surface lunge feed”, “tonal blow”, “breach”, etc. Others, however, require inference and such observations therefore involve uncertainty. Hopefully, the breath intervals we record will reveal whether surface and dive patterns are reliably consistent cues for our designation of behavior codes. The cues used to infer ambiguous behaviors are outlined below.

We consider a humpback whale to be “Traveling” when it is moving in a directed, unchanging course with fairly regular and relatively brief dive intervals and surface sequences, a moderate to fast pace, and predictable movements. In such cases, the direction of travel is also noted. Options: Fast Travel, Slow Travel.

“Milling” whales have no directed course and seem, well, bored. This category is admittedly a catch all that encompasses social behavior, robust behavior like (aerials, chin slaps, pec-slaps), and possibly foraging/exploratory dives in search of suitable prey patches. Sightings assigned to this behavioral category will be scrutinized alongside the acoustic backscatter and dive-ventilation data to infer more specific behaviors.

We consider a whale to be “Resting” when it is either still or moving at a very slow, directed pace. Breaths are not boisterous, fluking may be uncommon or non-existent, and dives will be short (or not occur at all). We consider a whale to be “Sleeping” if it is absolutely still, like a log floating on the surface, never or barely fluking and completely unresponsive to nearby vessels.
Dall’s Porpoises and killer whales exhibit fairly obvious feeding behavior because their speed dramatically increases and the pod circles and moves in sporadic directions. However, knowing when a large whale is “foraging at depth” (“FED” in the data entry program) is more difficult, but given the objectives of our study, it is also among the most important behaviors to record.

A humpback is considered to be foraging at depth when most or all of the following behaviors are observed: her travel pattern is circuitous or back-and-forth; her dives are long; her surface sequence comprises relatively many breaths and she is surprisingly still at the surface (i.e. recovering); her first breath after a dive is inordinately boisterous and the subsequent breaths are inordinately small; and she changes her orientation right before she flukes and dives. There are exceptions to this, of course. Humpback whales sometimes rove in large groups with intimidating energy, performing short dives and traveling in tight circles; in such scenarios it is likely that the whales are corralling a shallow prey school and group-lunge-feeding below the surface. Other times, when humpbacks are feeding in very shallow areas or along the shores of islands, dives will be very short, and their surface sequence may consist of only one or two breaths before fluking for another short dive. This is also, almost certainly, indicative of active feeding.

Mother humpbacks and their calves are often exceptions to these rules. They often do not fluke, and even when traveling they make unexpected turns to attend to their calf. However, it can be obvious when a mother is feeding at depth, because she leaves the calf to dilly-dally at the surface while she goes “to work”. She often surfaces minutes later quite far from the calf, at which time the calf rushes over to her; it is not uncommon for one or the other to tonal blow, pec-slap, or exhibit other robust behavior. It seems like the calf can never correctly guess where the mother is going to come up next. We have seen calves become distracted by kelp beds and sea lions only to distance itself further and further from its foraging mother; invariably the calf would eventually realize this distance then rush straight back to the place the mom last surfaced.

Behavior Assignment - Fin whales
Fin whales can be more difficult in some respects. The “Traveling” and “Resting” cues used for humpbacks also apply to fin whales, but the travel speed changes significantly. The Bangarang could reliably catch up to any humpback sighting, but a group of fin whales (the fastest great whale, the “Greyhound of the Sea”) traveling earnestly would be unreachable. Likewise, a sporadically surfacing fin whale that is probably foraging at depth can be extremely difficult to keep up with. Like humpbacks, feeding fin whales reliably change directions right before their dive, though the new direction is more difficult to predict. Fin whales can also be more skiddish, able to surface once and never be seen again if they so choose. Conversely, they can also be more curious, sometimes turning right toward the vessel and forcing us to a halt while they give us a thorough inspection. In general, in my limited experience, their behavior is far less stereotyped and more subtle than that of humpbacks.

That said, one noticeable cue of deep feeding in fin whales is travel patterns of great circles and long dives. Often I would give up trying to predict where the fin whales would surface next, only to find that they would eventually circle right back to my vessel. This foraging behavior has been noted elsewhere (Allen et al. 2011; Janie Wray 2013 pers. comm.). Though I do not yet have the data to support it, it seems that the majority of the time they are circling to the right, the same side that bears the white lower mandible.

Acoustic Prey Mapping
Active acoustic sampling is conducted for a minimum of 150m horizontal distance within 150 of the whale(s). Our target is 5-15 minutes of acoustic prey mapping with each large whale. This is not done in the presence of odontocetes. After (or while) identification photographs and breath intervals are being taken, I navigate the vessel in a “mini-transect” zig-zag that follows behind the whale’s general direction of travel. If the whale is surfacing erratically and its course cannot be predicted, these mini-transects are abandoned and the vessel keeps a safer distance.

Dive-Ventilation Metrics
Dolphin (1987) assumed that ventilation cycles (from the dive stroke of a whale, through the dive, through its
surface period and up to the initiation of the subsequent dive) rather than individuals were units of replication. Here I will do the opposite. My objective is to record at least one full ventilation cycle for each individual in each sighting. If I observe multiple ventilation cycles in a single whale I may average the measurements to produce a single data point. If the sighting is of a group that is comprehensibly traceable, I monitor the ventilation behavior of up to 3 whales at a time. If not, I select a distinct whale that is easy to track in the crowd (after Jahoda et al. 2003). Following Dolphin (1987), Wursig et al. (1984) and Dorsey et al. (1989), I do not record breath intervals of calves.

What Is Measured
Ventilations are logged into the data entry program within 0.01 minutes of their blow. During a close approach the following events are logged in the data entry program with gps- and time-stamps:

Start of surface sequence
Breath
Dive stroke
Surface synchrony with other group members (Y/N for a surface period, dive stroke and return to the surface; to my knowledge this is a novel metric).
Frequency of presenting flukes during dive stroke (for humpbacks only; Y/S (sometimes)/N).
Play: whether robust behavior or play is observed, e.g. aerials, pectoral slaps, tail slaps, etc. (Y (only behavior exhibited) / S (occasional robust behavior) / N).

Other buttons are available in the case of observer error: Missed breath, Cancel breath, Cancel dive stroke, Clear record and re-start DV record, or change assignment of behavior to a different individual. These notes allow some breath metrics to be salvaged even when others are lost due to distractions or problems in the field.

From the above entries the following dive-ventilation metrics (DVMs) are derived:
Total duration of the dive (DT)
Duration of surface period (ST)
Number of blows during the surface period (NB)
Breath intervals (BI)

What Is Calculated
From these, the following are calculated:
Mean blow intervals (MBCI): Surface time / number of flows, or ST / NB
Overall blow rate (BR): Number of blows / total ventilation cycle, or NB / (DT + ST)
Surface blow rate (SBR): blow rate as a function only of the time spent at surface (inverse of MBI).
PCST: Percent of ventilation cycle spent at the surface, or ST / (ST + DT) X 100

Each night while sightings are still fresh in mind, all breath intervals from the day are reviewed and corrected as needed. Following Dolphin (1987), the following rules are applied to the observations: Any period for which BIs is greater than 1.5 minutes is designated as a dive post-hoc – unless the whale was visible near the surface (i.e., sleeping). Jahoda et al. (2003) used a log-survivorship analysis to distinguish between breath intervals and dives (after Fagen and Young 1978). DT was begins with a “dive stroke” (for humpback adults this usually means display of a fluke) and ends with its next appearance at the surface (be it a breath or a breach or some other robust behavior). When the surface period includes only one blow the mean BI is given the value 0.1.

In case his presence altered the ventilation behavior of the whales he was tracking, Dolphin (1987) deleted the first 25 minutes of respiration data. I do not have the time to practice this precaution, but I am very attentive to the response of whales to my presence. If I suspect a reaction to me I will make note of it and usually abandon the sighting.

Travel Patterns
The whale being tracked for ventilation will also be tracked spatially. Each time the group surfaces, the whale whose ventilation is being tracked will be ranged with a handheld laser rangefinder. The crew handling this will obtain the range to the animal and its bearing from the bow of the vessel and call the data out to Eric. These travel patterns will be used to calculate the following for each focal follow:
Index if Linearity: the ratio of the straight-line distance between initial and final tracking point and the total distance traveled during the tracking period

Ranging Index (after Jahoda et al. 2003): The diagonal of the minimum area that includes the whale’s course, weighted by the duration of the tracking period (T):

\[
\text{Ranging Index} = \frac{\sqrt{(LAT_{\text{max}} - LAT_{\text{min}})^2 + (LONG_{\text{max}} - LONG_{\text{min}})^2}}{T_i}
\]

Photo-ID

Photo-identification efforts can supplement or even supplant abundance estimates derived from distance sampling. Mark-recapture methods can be advantageous for species whose individuals are distinctly marked (Dawson et al. 2008), because it can produce precise abundance estimates relative to distance sampling, generally has fewer boat requirements (raised sighting platform not needed), and can also position researchers to collect other demographic, behavioral, ecological, and health-related data (Dawson et al. 2008).

Photographs are taken with a Nikon D200 with 100-300mm zoom lens and a Canon 7D with a 400m zoom lens. A Canon Rebel XT with a Sigma 100-300mm lens is also on board as back up. The software Photo Mechanic is used to import images, re-name image files, apply the appropriate metadata, and single out the best research images. Photo-ID catalogs for resident orcas, humpbacks, and fin whales are on board. An energy-efficient 19” LCD monitor is inset in the salon wall for use in photo identification work. Downloading and processing images is a nightly task on board (see Data Management, p. 27).

Samples

Samples of scat, skin, scales, feathers and other remains at the surface are collected opportunistically using a telescoping (8-23 ft) pole with a pool skimmer attachment modified with 333micron Nitex mesh. These samples are preserved in alcohol, documented similar to the zooplankton samples, and kept in a freezer (12VDC, Engel 14 quart fridge-freezer) until they can be transferred to a larger freezer at NCCS headquarters or Hartley Bay. Samples are sent to DFO for DNA and isotope analysis.

When balls of forage fish or adult euphausiids are found near the surface, I used a cast net to attempt collection (after Gulf Watch, JF Piatt, USGS Science Center\(^6\)).

Passive Acoustics

This is of higher priority with fin whales. If conditions and location allow us to shut off the engine, at least 10 minutes of acoustic recording are sought during a fin whale closure. The engine remains running for humpback and orca sightings unless the group is vocally very active.

\(^6\) http://www.gulfwatchalaska.org/monitoring/pelagic-ecosystem/forage-fish-2/
Returning to the Trackline

Unless the vessel is within 0.2 km from the end of the transect line, the Bangarang will return to the point (within 0.5 km) from which it broke transect to close on a sighting (as recommended in Dawson et al. 2008). “On Transect” effort searching is not resumed until the ship has come up to survey speed and there is no chance of mistaking the previous sighting for a new one. Either all individuals from the sightings are left behind the vessel before resuming searching effort or the locations of remaining subgroups forward of 90 degrees are dutifully tracked.

Until the transect line is reached, effort is “Casual” and observers use this time to stow the cameras, snack, rest, and brace themselves for the remainder of the transect. Once transect effort is resumed, if a school that has been previously seen and entered as an off-effort sighting is seen again, a new sighting event is entered for the school. Both the original off-effort and subsequent on-effort sighing-events are retained, with comments in the database and on the sighting forms that they were the same school. School size and composition estimates proceed as usual, in off-effort mode if necessary.
Tidal-Trophic Event Transects

The above study design of repeated circuits examines interactions and associations on relatively large scales in space and time. However, there may also be oceanographic features on the scale of hours and at specific topographic features (e.g., sills) that make the Kitimat Fjord System a unique and important foraging ground for whales and seabirds.

The methods I describe here pertain to a specific study that will be conducted in 2014. It takes a closer look at the fine-scale coupling of trophic interactions and the physical environment by focusing on tidal-trophic dynamics in focal corridors within the study area.

Site Selection

From the 2013 feasibility study I identified four constrictions within the study area that a) exhibit vigorous tidal mixing, especially during spring tides; b) reliably host large multi-taxon feeding aggregations; and c) are representative of the diversity of environments and communities to be found in the study area. The following focal corridors were selected:

1. **Parker Pass**: Near the outer shores of the fjord system, Parker Pass is a long, shallow, skinny, non-silled corridor that is heavily influenced by oceanic waters. All of the area’s marine mammal species are known to use the area, including a resident group of bubble-net feeding humpbacks.

2. **Casanave Pass**: Moving inland, Casanave is a short, shallow, skinny, silled corridor that occurs at the confluence of 3 oceanographically distinct channels. All of the area’s marine mammal species use this area. A sea lion haul-out rock occurs adjacent to the passage.

3. **Lewis Pass**: Similarly inland is Lewis Pass, a long, relatively deep, non-silled constriction that links Squally Channel and Wright Sound. It is used heavily by both fin whales and humpback whales and is one of the most technically difficult and confined sections of the proposed tanker route.

4. **Verney Sill**: Deep within the fjord system at the intersection of Verney, Gardner and Ursula channels an extremely shallow (30m) sill constricts the broad corridor. This sill reliably generates standing surface waves during spring tides. Influenced greatly by freshwater discharge, this area is used heavily by humpback whales in the fall.
Field Methods
In each month of the 2014 season (June – Sept.), I will collect data in each pass during the two 3-day windows around each month’s spring tides⁹. At each pass, I will transit a 3km transect hourly (7 times) throughout the duration of ebb tide, from midday high-water slack to evening low-water slack (after Cummins et al. 2003). Transects will be conducted from north to south with the ebbing current at a target speed of 4.8 knots (transit time approx. 20 minutes). Yo-yo CTD casts will be conducted throughout each transect (target of 4 profiles per transect). Visual and echosounder transect methods will be the same as those in the General Methods above (but the echosounder depth range will be set to 100m). Observers will photograph flocks to 1) constrain estimates of group size and percent species composition post hoc and 2) obtain visual evidence of prey species in beaks. During the return transit between transects, surface currents will be measured with a flowmeter and corrected using the vessel’s known GPS speed. Interesting sightings will be investigated and prey remains will be collected wherever possible.

Data Entry & Management
During the day, data are entered into a homemade computer program, Research Underway: Bangarang (“RU Bangarang” or “RUB”) on a laptop mounted atop the helm stand. The laptop is touchscreen for ease of use in glare and cold; see RUB User’s Manual.

RUB automatically records the date, time, GPS (provided by a US Global Sat USB antenna), sighting conditions, effort mode, and observer positions for every piece of data entered, vastly expediting the process of entering and analyzing data. Time and position data for each sighting are typically logged within 2 seconds (delay of .04 minutes or ~5 meters) of the sighting report.

Standardly formatted lines of comma-delimited data are stored in a single text-file throughout the day. Each night, the day’s output file is reviewed for errors: faulty GPS readings, flagged regions of the code, and post-hoc sighting data updates are corrected. The original output is archived but a copy is amended with corrections. The revised output is then backed up in multiple places. This “RUB daily” is then sieved with an R routine into several .csv files according to their category (e.g. a Secchi disk .csv file, a seabird sightings .csv file, etc.). Breath intervals and sightings data are then reviewed for accuracy. Weekly data packages and maps will be compiled automatically and made available to collaborators and advisors.

CTD data are recorded in the CTD itself throughout the day, then downloaded via bluetooth to laptops in the evening. Tidal data will be retrieved from the DFO website following the season; high-resolution bathymetric data are being obtained from the Canadian Hydrographic Office. Hydrophone recordings from the day are scanned systematically each night using spectrographic displays in Raven; recordings are viewed at both "zoomed out" (0-16 kHz) and "zoomed in" (0-80 Hz, for fin whales) displays. Images are uploaded to a computer, renamed, and assigned metadata using the software PhotoMechanic. The best fluke and dorsal shots from every whale sighting are saved to a “Cetogram” folder, which is then passed on to NCCS, DFO and the Guardian Watchmen after each circuit (every two weeks or so). Digital and paper catalogues of locally seen humpbacks, orca, and fin whales are on board. The salon’s research monitor can be used to identify whales as a team.

Two 1TB external hard drives are stowed on board for data back-up. Each night, photographs, RUB output “dailies”, acoustic recordings, and echograms are backed up to the “WIF-1” hard drive. These data are also stored on their original locations (the Macbook Pro in the case of the photographs; the Toshiba in the case of the echograms; and the Samsung for RUB Dailies). At the end of every circuit, all forms of data – being reviewed, finalized, and packaged – are backed up on both “WIF-1” and “WIF-2” hard drives.

⁹ This year, full moon is forecast to occur between the 9th and 12th of each summer month; new moon is 19th-23rd. Recognizing that weather may not cooperate, my targets are 1) each month, visit 3 of the four sites within my 6-day window each month; and 2) successfully sample for 3 of the 4 months.
Literature Cited


Lgerwell and Hargreaves (1996)


Pennycuick, C.J. 1982. The flight of petrels and albatrosses (Procellariiformes), observed in South Georgia and its vicinity.)


