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Original research article

Collaborative research praxis to establish baseline ecoacoustics conditions in Gitga'at Territory

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ABSTRACT

This paper combines methodological discussion and scientific analysis to convey the results of an effort by the Gitga'at First Nation and academic partners to construct an acoustic baseline in Gitga'at Territory (aka. British Columbia, CA). Between June 2013 and 2014, we collected 257,327 field-recordings from eight sites as part of the Gitga'at Ecological and Cultural Monitoring Program. Our goals were: (1) to develop an acoustic baseline in a portion of Gitga'at Territory prioritized by local decision-makers, (2) to advance Gitga'at research capacity through the collaborative and reflexive structure of our approach. We argue that reorienting ecological knowledge production as praxis-based "Street Science" benefits resource management, as well as academic and local community interests. Gitga'at oral histories (*adawx*), and laws (*ayaawx*) guided our application of soundscape ecology, including our use of the normalized difference soundscape index (NDSI). Our results suggest Gitga'at Territory is a diverse acoustic-ecological space with numerous site-specific features. Significant differences were found between recording sites, with the greatest amount of biological activity noted June and July. We also found that the frequency and intensity of anthropogenic noise (i.e., technophony) in the Territory is currently very low, suggesting a low degree of anthropogenic disturbance. We conclude that soundscape ecology is well-suited for collaboration with indigenous communities, provided it is 'attuned' to the complex terms of engagement that constitute cross-cultural research.

1. Introduction

A vast majority of the conservation research conducted in the world today takes place on indigenous lands, yet operates at a significant remove from the peoples who reside there. The challenges indigenous communities confront in efforts to effectively feature in conservation research can be myriad (Smith, 1999). Competitive timelines, budgetary constraints, and specialized disciplinary interests dissuade researchers from forging ties with interested local groups (Adams et al., 2014). All too often, the consequence is a double-loss: indigenous communities are barred from important sites of local knowledge production while scientific efforts to study lands, waters, resources and biology omit vital bodies of skill and understanding.

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This paper discuss how a soundscape ecology project was established as part of the Gitga'at Ecological and Cultural Monitoring Program, and specifically to advance the conservation interests of the Gitga'at Nation, an indigenous people whose Territory overlaps geographically with British Columbia's North Coast. Our study centered on building a baseline of sounds in Gitga'at Territory. The Gitga'at Nation is particularly interested in understanding the acoustic composition of the Douglas Channel-part of the Territory (Fig. 1), as this region has lately been proposed as a conduit for potential shipping activities (Bocking et al., 2011). We contend that soundscape ecology is ideally suited to assist the community with these concerns, as soundscape ecology considers the aggregate sounds of given landscapes in terms of acoustical patterns at a variety of spatial and temporal scales (Pijanowski et al., 2011). Growing interest in sound as a medium for the study of ecological processes (Mullet et al., 2015; Sueur and Farina, 2015) is being facilitated by advances in user-friendly eco-acoustic measurement technology (Wildlife Acoustics, 2015). The ecological impacts of increasing levels of anthropogenic noise are receiving increased public interest as well (Tennessen et al., 2016). Merchant et al. (2015) suggest that the use of passive acoustic monitoring (PAM) can enhance understandings of sound's ecological function in a range of contexts, and has the potential to inform efforts to mitigate the rising influence of anthropogenic noise in these ecosystems. Keeping this dual-use goal in mind, our study sought to examine the patterns of sound at the terrestrial–ocean interface, both a novel site of inquiry for soundscape ecology and site of pressing concern for a marine-dependent Gitga'at community.

We were surprised to discover an absence of soundscape ecology work at the interface of indigenous-settler collaborations. Place-based listening has been shown to be a vital source of indigenous knowledge (Basso 1996) and disruptive anthropogenic sounds can lead to major cultural-use impacts within indigenous lands (Henricksen 2009). We suspect that very often, indigenous communities simply endure acoustical impacts as part of the cumulative effects of industrial development; one component of the "slow violence" that includes multiple stressors of greater and lesser state-institutional legibility (Nixon, 2011). There is critical need for research at the intersection of soundscape ecology, and indigenous-led collaborative science. While there is now ample (and deserving) scientific inquiry into the catastrophic effects an oil spill would have on the Gitga'at community (Bocking et al., 2011; Chan, 2011), the potential impacts of chronic low frequency tanker noise on terrestrial and coastal ecologies remain undocumented. Of particular concern for Gitga'at is the Enbridge Northern Gateway Project (ENGP), a multi-billion-dollar transportation project that would send over two hundred tankers through territorial waterways annually (see Fig. 1). There is now a considerable literature profiling the ecosystem impacts of chronic anthropogenic noise in related contexts (see Reijnen and Foppen, 2006; Rheindt, 2003; Nowacek et al., 2007). Deleterious physiological and behavioral responses to chronic low frequency noise have been observed in birds common to Gitga'at Territory (Slabbekoorn and Peet, 2003; Fuller et al., 2007; Goodwin and Shriver, 2010). Regional management plans identify marbled murrelets (*Brachyramphus marmoratus*) as "important marine wildlife species" (Yen et al., 2004), and avoidance patterns of marbled murrelets have been correlated to noise and increased vessel traffic (Hamer and Thompson, 1997). Various animals could be impacted by noise created under "routine operations" of large shipping (and the Enbridge NGP in particular) in Gitga'at Territory (Bocking et al., 2011). There are thus numerous pathways linking the noise of marine industrialization to potentially system-altering impacts on Gitga'at livelihood practices. Community concerns about possible eco-acoustical changes in the Territory were a major reason we were invited to conduct our research in Gitga'at Territory (08/07/2013).

Between June 2013 and 2014, our team collected 257,327 field-recordings from eight sites in Gitga'at Territory. Our goals were to: (1) develop an acoustic baseline in Gitga'at Territory along a marine corridor that faces the prospect of intensive industrial development and (2) advance Gitga'at research capacity through whatever means our study made available. As we show here, the terms of our contribution to Gitga'at could not have been predetermined; it was only through a reflexive approach that the emergent interests, understands, and skills of the community could be known and incorporated within the context of our research. This approach was not without challenges, and may not be duplicable in contexts where the research parameters are too narrowly set. Nevertheless, we contend that soundscape ecology is well suited for collaboration with indigenous communities, insofar as the project is 'tuned and retuned' to the complex terms of engagement that constitute cross-cultural research.

Context: To understand how our methodological procedures developed, it is necessary to consider the dynamic role of context in our project. Gitga'at Territory is the Gitga'at people's "ceremonial and political base"—a vital source of Gitga'at cultural knowledge, identity and renewal (Roth, 2008). It consists of a 14,000 km^2 expanse of land and ocean along British Columbia's North Coast. Much of this temperate region is classed as Coastal Western Hemlock (BC CDC, 2013), and includes significant stands of hemlock and western red cedar in addition to many species of vascular plants, mosses, fungi and lichens (Fissel et al. 2010). To maintain effective stewardship over Gitga'at Territory, the Gitga'at have undertaken a range of conservation efforts rooted in Gitga'at traditional knowledge, foundational oral histories (*adawx*), and laws (*ayaawx*). One of us (CP) is Science Director for the Gitga'at Nation, and oversees the Gitga'at Ecological and Cultural Monitoring program (Gitga'at, 2014). This program is designed to support Gitga'at core values of improving conservation, asserting rights and title, enhancing stewardship and resource management decisions, and ensure that the traditional Gitga'at way of life is protected by increasing knowledge and understanding of the Territory. By pursuing our efforts under the ambit of the Ecological and Cultural Monitoring program, our study was well positioned to incorporate the insights of Gitga'at community members.

Ecologists and policy-makers are increasingly recognizing that indigenous-led approaches to ecological conservation can achieve relevant, sustainable outcomes in resource management (Deur and Turner, 2005; Ban et al. 2008; Ostrom, 2009; Housty et al., 2014). When scientific research is respectful of multiple knowledge forms and values, science can be usefully

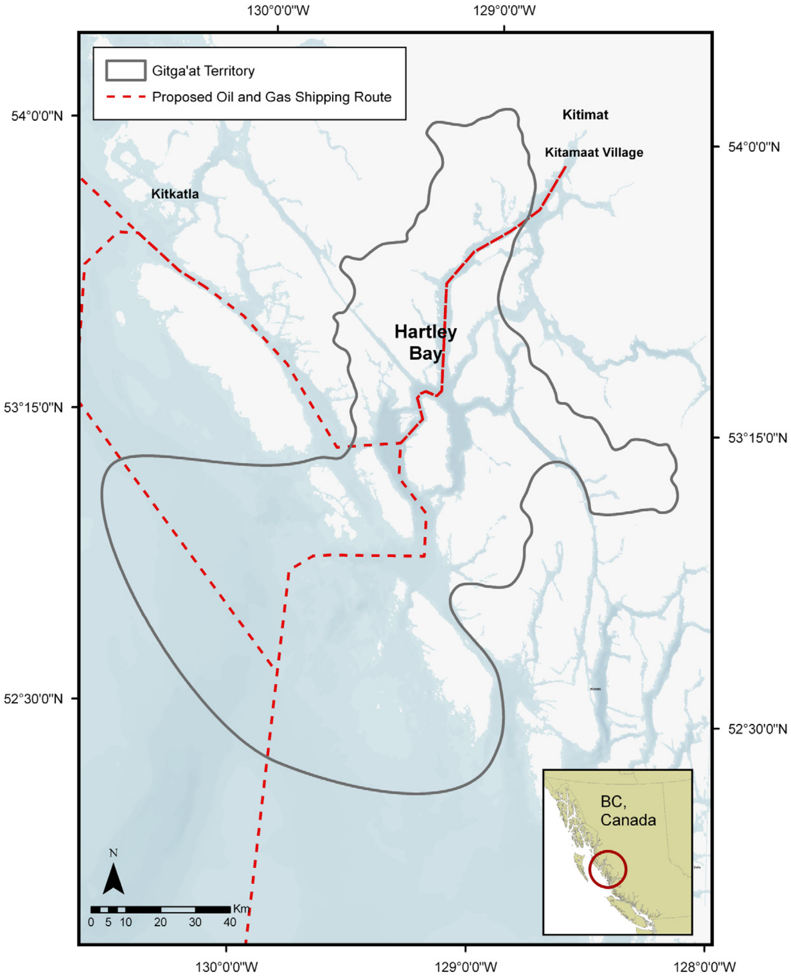

Fig. 1. Extent of the Gitga'at core traditional Territory. Credit: Kim-Ly Thompson.

incorporated into indigenous-led resource management systems (Clark and Holliday, 2006). There is pressing need to develop such engagements in partnership with indigenous people, whose Territories comprise some of the highest priority areas for conservation in North America (Oviedo et al., 2000). This effort take inspiration from the recent work of Housty et al. (2014), which powerfully demonstrates how the situated application of bear conservation science in Heiltsuk Territory (<200 km south of our study site) can extend from indigenous teachings and principles. As Housty et al. (2014) explain, indigenous-led approaches to land and marine conservation comprise complex arrangements of local and traditional ecological knowledge (cf. Brown and Brown, 2009). Accordingly, scientific 'collaboration' with indigenous communities must mean more than handing recorders to community-members and asking them to input data into predetermined spreadsheets (Wainwright and Bryan, 2009). Collaboration must proceed in reflexive engagement with – if not incorporating of – local knowledge; producing work that challenges traditional hierarchies of scientific expertise by exposing interpretation and analysis to perspectives science has historically marginalized. In the next section, we discuss how we sought to combine scientific research with methodological commitments appropriate to our research context.

2. Methods

Street Science: Citizen Science (CS) approaches to conservation efforts are now receiving widespread attention (Cooper and Balakrishnan, 2013; Shirk and Krasny, 2012; Hopkins and Freckleton, 2002). In this project, we followed a model put forth by Corburn (2005), which proposes CS-style research 'praxis' rooted in the empowerment of local actors and the democratization of knowledge—Corburn terms this 'Street Science.' Noteworthy for our purposes is the value "Street Science" places on local knowledge, defined simply as "the accounts, stories, tests, and practices of residents" (Corburn, 2005, p17). Corburn's two-pronged argument is that local knowledge can benefit professional techniques, but that accessing and deploying this knowledge effectively is not straightforward. With its attention to the political economy of knowledge production, Corburn's idea directly engages several of the key issues raised of the more encompassing CS—including the tendency to leave problematic knowledge-hierarchies unquestioned (Burke and Heynen, 2014). Although he does not explore indigenous-settler collaborations explicitly, Corburn outlines ethical considerations and knowledge-sharing principles that are highly amenable to such contexts. Questions of respect, goal-orientation, and information sharing must be patiently and carefully negotiated, often with concessions and alterations to project design. Researchers must be constantly engaged with their collaborators, not in terms of paternalistic 'research leaders' and 'followers,' but as a heterogeneous body of differently-skilled individuals and social collectivities (cf. Castleden et al., 2012).

Gitga'at leadership presented our team with a unique opportunity to combine "Street Science", soundscape ecology, and community engagement in Gitga'at Territory. Our challenge was to develop the critical insights of soundscape ecology while simultaneously applying and honoring Gitga'at community knowledge and capacity. Gitga'at histories (*adawx*), and laws (*ayaawx*) guided the framing of our questions and the application and utility of our results in several key ways, including:

- Establishing Gitga'at Territory as the operative research scale;
- Developing non-invasive research that presents no risk of disturbance to wildlife and culturally sensitive land-use areas in Gitga'at Territory;
- Pursuing a research-ethics more focused on leaving knowledge in the Territory and not taking it away;
- Organizing all recording locations in consultation with Gitga'at elders and maintaining constant dialogue with the community throughout

The waterways of Gitga'at Territory are notoriously inclement during winter months, and unpredictable through the year (Ban et al. 2008). We relied upon local knowledge of weather conditions, waterways, and animal habitat use to guide our data retrieval procedures. Throughout the data-collection period, we solicited local knowledge with the goal of integrating traditional ecological understandings into our consideration of site-specific baseline features. As the research developed, we were grateful to receive growing interest from Gitga'at community members. The following is a summary of the ways community participation shaped our efforts:

- Greater 'socialization' of soundscape ecology knowledge (e.g. community presentations at the Hartley Bay high-school);
- Collaboration and resource-sharing with community conservation authorities (i.e. Gitga'at Guardians);
- Use of Traditional place names in place of government of Canada place names, to identify sites and communicate information in all published materials;
- Incorporation of Gitga'at community members into the project as field-technicians and researchers;

Community directives re-focused our soundscape project and strengthen its community value. We contend that they are expressive of a research model (i.e. "Street Science") that explicitly seeks the capacity of local knowledge to empower science. Further illustrating this model-in-action, we were asked mid-way through the data-collection phase (02/11/2014) to employ two high-school students (Ethan Dundas and Steven Dundas) as primary field research support. The episode elicited the realization that our soundscape research project could assist Gitga'at in preparing young people for socially ordained roles as stewards of their Territory. This community-led decision proved expeditious to our efforts, as Steven and Ethan's knowledge of the Territory made it possible to access field-sites during inclement weather conditions and to conduct management of our eight sound recorders.

Acoustic monitoring: Our study used SM2 Song Meters to record ambient sounds in Gitga'at Territory (Wildlife Acoustics, 2015). The units were programmed to record for 1 min at 15 min intervals. Recording features were set at 22,050 Hz in 16 bit monaural, wav file format. This automated soundscape monitoring protocol allowed us to record phenomena during adverse weather conditions (e.g. nocturnal, high rain), when human traffic is generally restricted in the Territory. Given our context, a major noted advantage of the SM2 sensors is their ability to automatically collect non-invasive data. This aspect eased community concerns about the possible ecosystem-altering effects of our long-term monitoring efforts. To ensure no harm to trees in Gitga'at Territory, SM2 units were temporarily fixed to trees near coastlines (at high-tide) using bungee cords. Batteries and SD cards were exchanged at monthly intervals depending on weather conditions prior to battery depletion or SD card saturation.

In consultation with Gitga'at decision makers, we selected eight recording sites along a planned shipping channel. Fig. 2 shows sensor location and the place names in traditional Gitga'at language, *Sm'algyax*. These sites represented a balance of high ecological values and community-interests. The soundscape monitoring sites are located along the shipping route proposed to be used by numerous hydrocarbon export projects that falls within core Gitga'at Territory, roughly from the northern side of *Ksuwii* (Maitland Island; HB07) to the head of *Lax k'ak'aas* (Campania Island; HB04). Gitga'at knowledge of tidal conditions allowed us to optimize site locations, enabling the recording of three featured components of the soundscape concurrently: coastal biophony (e.g. sounds of birds and marine mammals), geophony (e.g. sounds of waves, wind, rain) and technophony (e.g. sounds of boats, aircraft).

Data management and updates: We collected and archived 257,327 recordings from June 2013 to July 2014. Only 522 recordings were made in February due to inclement weather, which impaired boat access to sites and hence precluded the ability to exchange batteries and SD cards. The recording hardware at Site HB02 became dysfunctional between March and June, 2014 and was replaced in June 2014 (see Table 1).

To keep community members informed throughout our data collection efforts, we established an online inventory of the recordings using the REAL web system (www.real.msu.edu), and made accessible by a password specific to the Gitga'at

Fig. 2. Map of sound recorder locations along the planned shipping channel using traditional place names. Credit: Kim-Ly Thompson.

Table 1
Monthly distribution of digital acoustic recordings collected from each of eight sites, archived and analyzed from June 2013 (month 1) to July 2014 (month 12).

Month	Year	HB01	HB02	HB03	HB04	HB05	HB06	HB07	HB08	Total
1	2014	2 861	2 958	2 858	2 854	2 951	2 209	2 894	2 850	22 435
2	2014	128	3	132	133	0	0	0	126	522
3	2014	2 976	0	2 976	2 976	2 714	2 717	2 720	2 976	20 055
4	2014	2 880	2	2 880	2 880	2 880	2 880	2 880	2 880	20 162
5	2014	2 972	0	2 972	2 976	2 972	2 972	2 972	2 972	20 808
6	2013–14	2 395	509	3 461	3 393	3 402	3 404	3 405	3 408	23 377
7	2013	2 976	2 976	4 451	4 446	4 478	4 491	4 495	4 465	32 778
8	2013	2 976	2 976	2 976	2 976	2 976	2 975	2 862	2 975	23 692
9	2013	2 880	2 880	2 880	2 880	2 853	2 856	2 856	2 880	22 965
10	2013	2 976	2 976	2 976	2 976	2 937	2 933	2 935	2 976	23 685
11	2013	2 880	2 880	2 880	2 880	2 880	2 880	2 880	2 880	23 040
12	2013	2 976	2 976	2 976	2 976	2 976	2 976	2 976	2 976	23 808
Total		31 876	21 136	34 418	34 346	34 019	33 293	33 875	34 346	257 327

community. The web-based Hartley Bay project featured project metadata, and specific coordinates of each sensor site and the habitat surrounding the site. Recordings were copied to disk and periodically accessed by a rotating team of Gitga'at Guardians and overseeing investigator. Soundscape computations were made prior to storing the recording and their associate metrics into the REAL database where the sounds and the metrics can be accessed (Kasten et al., 2012).

Analysis of soundscape recordings: We computed normalized Power Spectral Density (nPSD) values for 10 frequency intervals (F1–11 kHz) captured in our recordings sites, rendering each interval with a value 0–1. We computed totals of the nPSD values, technophony (nPSD at F1–2 kHz), biophony (nPSD at $\sum$[F2–11 kHz]) and the normalized difference soundscape index (NDSI) where the NDSI $= (b-t)/(b+t)$ and where $b =$ PSD $\sum$(F2–11 kHz) and $t =$ PSD(F1–2 kHz). The NDSI values can range from -1 to $+1$ where -1 is indicative of the dominance of very low frequency (usually technophony signals) and a value of $+1$ is indicative of the dominance of very high frequencies (very high biophonies) (see Kasten et al., 2012; Gage and Axel, 2013; Fuller et al., 2015). It is important to note that an anthropocentric bias is written into our tools and accompanying NDSI analytic (Mullet et al., 2015). We did not record frequencies above 22 kHz, and eliminated F0–1 kHz for analytic purposes. The absence of ultrasonic or infrasonic frequencies potentially omits relevant forms of biophony, geography and anthrophony, thus calling for follow up work.

Soundscape identification: Our baseline focused on the identification of bird species and dominant soundscape features (e.g. biophony, geophony, technophony), and sampled early morning and late afternoon, during the dawn and dusk choruses

Table 2
The frequency class and the value of the nPSD used to select the recordings for identification of the sounds within it.

Frequency (kHz)	Threshold (nPSD)
F1–2	>0.995
F2–3	>0.8
F3–4	>0.7
F4–5	>0.6
F5–6	>0.5
F6–7	>0.4

Table 3
The sounds targeted within the three components of the soundscape.

Biophony	Technophony	Geophony
Northern raven *Corvus corax*	Nearby boat	Strong waves
Bald eagle *Haliaeetus leucocephalus*	Distant boat	Strong wind
Marine mammals	Aircraft	Strong rain

in order to capture the greatest amount of acoustical activity. These features derived from community interests in culturally significant biophony, geophony indicative of adverse shipping conditions (e.g. 'strong wind'), and technophony indicative of extent shipping activity (e.g. boats). We identified the sounds that occurred in a subsample of the 257 327 recordings based on the value of the nPSD (which ranged from 0–1), as we wanted to sample sounds in each frequency class. Table 2 provides the frequency class and the value of the nPSD used to select the recordings for identification. We used the filtering system in the REAL web site to select the recordings and downloaded them to a desktop for audio identification.

After listening to a batch of recordings (∼75), we were able to consistently distinguish key species, as well as technophonic and geophonic sounds of interest. Table 3 shown the types of sounds identified within these three components of the soundscape.

3. Results

Our principal objective in analysis was to identify dominant patterns and key features in the acoustic baseline. We relied upon recent work in soundscape ecology to verify proposed classification schemes (Fuller et al., 2015; Mullet et al., 2015). Observed patterns of soundscape power (nPSD) for each of six frequency intervals (F1–F7 kHz) for the combined eight sites are shown in Fig. 3. Soundscape power values for each frequency interval have their own scale to indicate changes in soundscape power patterns within each frequency interval. Soundscape power is greatest at the lowest frequency (F1–2 kHz) and soundscape power decreases as frequency increases, thus reflecting our sampling protocol (see Table 2).

Soundscape patterns (all sites): Gage and Axel (2013) and Tucker et al. (2014) have shown that soundscape power in F1–2 kHz declines rapidly during the dawn hours, whereas higher frequencies show a distinct rise in power, due to an onset of songbird vocalizations (e.g. dawn chorus) (which generally occurs between F4–7 kHz). Other species of animals (amphibians, mammals and some birds) vocalize at lower frequencies, and their vocalizations are typically reflected in F2–4 kHz frequency intervals. Lower frequency sounds (F1–2 kHz) generally indicate technophony and tend to increase during the day and subside at dusk. In addition, soundscape power in frequencies >2 kHz tend to increase later in the day, when the increase in soundscape power at that time of day indicates the presence of a dusk chorus (see: Gage and Axel, 2013; Fuller et al., 2015). We found these general observations to hold in our present context. The patterns in soundscape power for each of six frequency intervals (F1–7 kHz) at 15 min intervals are shown for all sites and seasons in Fig. 3.

The normalized difference soundscape index, NDSI, is a useful indicator of the character of the soundscape. In this study, the NDSI presented a metric through which we could reflect differences in the soundscape at different times of day and within and across the study period. Higher values of NDSI reflect the presence of more biophony and lower values of NDSI reflect more technophony (Gage and Axel, 2013). For instance, evaluation of several soundscape indices in a recent Australian field study show that the NDSI is related to landscape attributes (patch size, conservation area, biocondition score, extent of roads) in addition to bird species richness (Fuller et al., 2015).

We plotted NDSI according to time of day and day of the year from March through December (due to the lack of recordings in February) to indicate changes in NDSI (see Fig. 4). During the early part of March and latter part of the year (prior to day 50 and after day 350), NDSI values were low, indicating few biophony acoustic signals (NDSI <0). Higher periods of NDSI (0.2–0.4) began to occur after midnight about day 120 and lasted until day 250. Biophony was most common between the hours of 0400–0900 h (dawn chorus) with a period of low biophony at about 1600 h (see Fig. 4).

Soundscape patterns (site specific): Analysis of the soundscape patterns in each of the eight sites (for each month of the year) reveals Gitga'at Territory as spatially and temporally differentiated by acoustic features. Again, this insight was generated by utilization of the mean NDSI index for each month (Fig. 5). During winter months (December–March), NDSI values were negative at many sites, indicating the dominance of low frequency signals (<0). Inclement weather in February, including

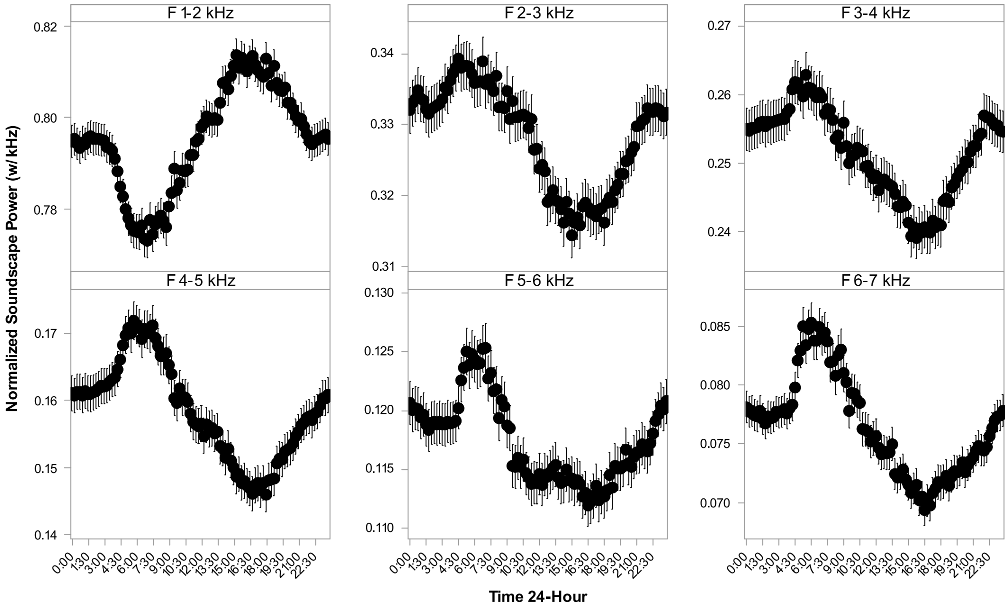

Fig. 3. Daily patterns of soundscape power (nPSD) at 15 min intervals for each of six frequency intervals (F1–F7 kHz) for the eight sites combined over the observation period (June 2013–July 2014) beginning at midnight.

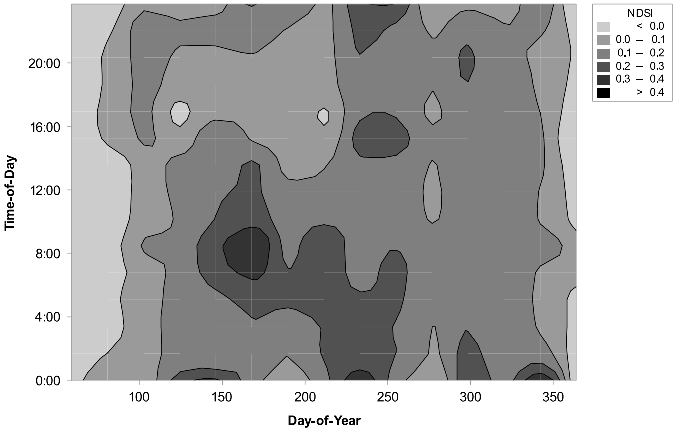

Fig. 4. Normalized difference soundscape index (NDSI) according to time of day (y axis) and day of the year (x axis) for all sites combined. Data from March through December were used to produce the figure. A low number of recordings were made in February due to inclement weather (see Table 1).

high wave activity in the Douglas Channel, prevented us from collecting data during this period. Observations in March revealed that 5 of our 7 sites had negative values of NDSI. By April, however, only site HB04 had negative NDSI values. During the summer months (May–August), all sites had NDSI values >0, indicating more biophony than technophony (with the exception of HB04 [0.01] and HB07 [-0.02]). In September–November, NDSI values for sites HB03 and HB04 were <0. In October–November, NDSI value for sites HB03 and HB04 were only slightly positive or negative (see Fig. 7). By December, negative NDSI values occurred in half the sites (HB01, HB03, H004 and HB08 (see Fig. 7)). Note that site HB04, the site with the most commonly negative NDSI values, was a site that was exposed to the largest amount of open ocean (see Fig. 1: HB01).

An 'Analysis of Variance' (ANOVA), comparing the mean value of the NDSI versus site, revealed significant differences between sites ($F = 3098.13$; $p = 0.000$). Tukey mean comparison ($p < 0.05$) revealed similarities between sites HB07 and HB06 as well as sites HB01 and HB03. Site HB02 was different and had a greater mean value of NDSI compared with the others. Site HB08 had a low NDSI value and was different from HB04 with site HB04 having the lowest mean NDSI (-0.172). The ranking of sites based on NDSI is shown in Table 4.

Soundscape patterns (day of year and time of day): There are two periods of the year and times of day when biophony typically occurs: beginning in mid-April and until 20 July; and from 0430 to 0900 h, (when the dawn chorus is most intense) (see Fig. 4). Biophony lasted for the entire day during this period at several of the sites.

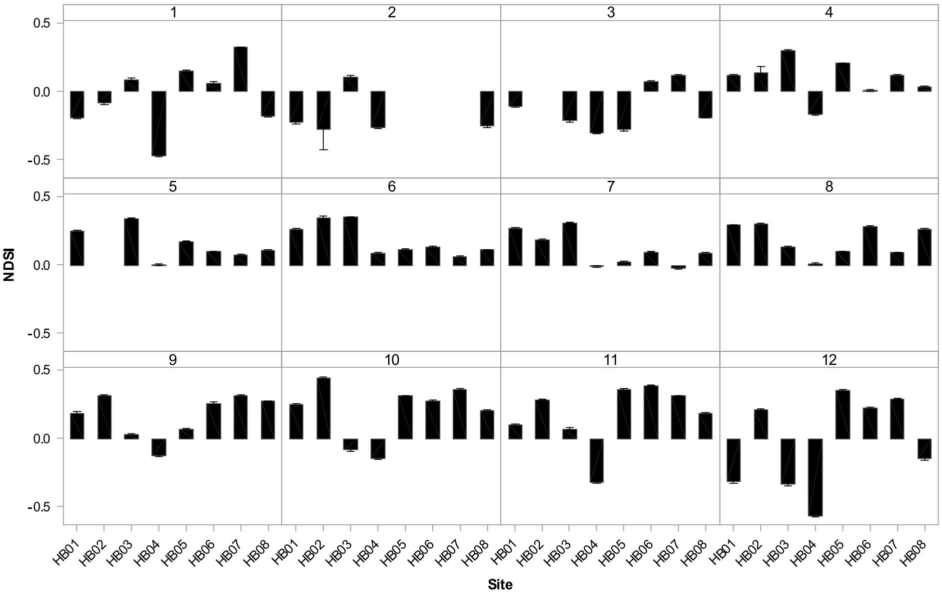

Fig. 5. Patterns of mean monthly values of NDSI for each of the eight sites. Note the missing observations for site HB02 and the low number of recordings made during February (2) due to inclement weather (see Table 1).

Table 4
Site code, number of recordings, mean NDSI site ranking and site difference based on the Tukey Method with 95% confidence where a common letter shows no significant difference between sites.

Site	*N*	Mean NDSI	Grouping
HB02	21 136	0.239	A
HB07	33 875	0.175	B
HB06	33 293	0.172	B
HB05	34 019	0.140	C
HB03	34 418	0.103	D
HB01	31 876	0.097	D
HB08	34 364	0.068	E
HB04	34 346	−0.172	F

4. Soundscape spectrograms

Spectrograms graphically display the frequency and duration of acoustic information in a given recording. Fig. 6 shows spectrographic examples of three soundscape entities considered as primary biophony: northern raven, bald eagle, and marine mammals.

Recordings identified: To further identify our recorded acoustic features, we listened to 5628 recordings, using predetermined identification criteria and soundscape types (biophony, geophony, technophony) (see Tables 3 and 5). These efforts were undertaken with Gitga'at Guardians as well as interested community members. Recordings examined and the count of each soundscape variable is shown in Table 5. No soundscape entities were identified from recordings made in January and February 2014, when sounds were almost entirely geophony (e.g. heavy wind and storm conditions).

A common concern raised in Citizen Science research is that novice 'bias' can weaken the validity of scientific claims. Recent scholarship has established that the solicitation of large number of users can counteract this (Lepetz et al., 2009; Jiguet et al., 2012). Our project relied on several sets of listeners of differing ages and skill sets to verify identifications. These included the project authors, Gitga'at Guardians, high-school students in Hartley Bay and a local expert listener (Dr. Reto Riesen).

The distribution of sounds emitted by northern raven, bald eagles, and marine mammals during March–December is shown in Fig. 7. For example, the northern raven was heard most often in July (12 times out of 143 recordings examined (0.084 ± 0.02), and occurred in lower numbers throughout the rest of the identification period. The bald eagle was heard 5 times in the 143 recordings in July (0.035 ± 0.015), and in selected recordings between May and October. The above-surface sounds of marine mammals (e.g., tonal blows, exhalations) were heard most often in August—in 259 recordings examined (0.0965 ± 0.0184)). Marine mammals in Gitga'at Territory include fin whales, humpback whales, killer whales or Stellar sea lions, all of which we group under a single category (marine mammal) in acknowledgment of our recorder-limitations.

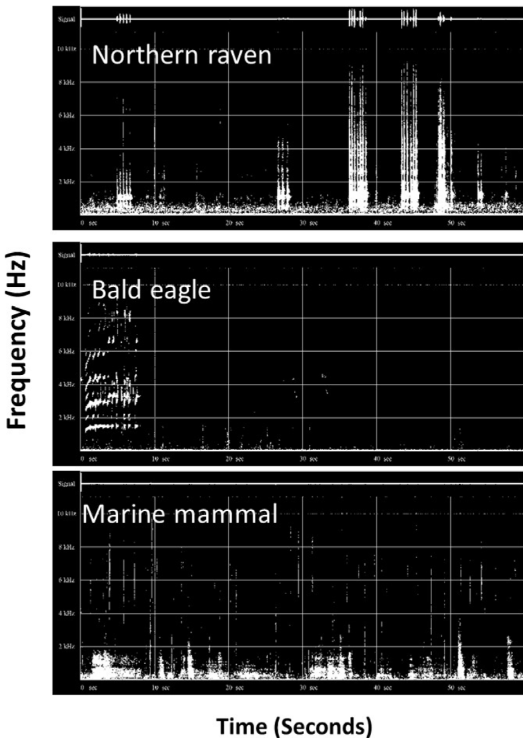

Fig. 6. Spectrograms of northern raven, bald eagle and (one) marine mammal.

Table 5
Soundscape variable, type, number of recordings examined and number identified.

Soundscape variable	Soundscape type	Recordings examined	Count
Northern raven	Biophony	5628	98
Bald eagle	Biophony	5628	48
Marine mammal	Biophony	5628	53
Nearby boat	Technophony	5628	39
Distant boat	Technophony	5628	45
Aircraft	Technophony	5628	13
Strong waves	Geophony	5628	413
Strong wind	Geophony	5628	370
Strong rain	Geophony	5628	902

We included nearby boats, distant boats and aircraft in the category of primary technophony (Fig. 8). At this point, the majority of boat activity through Gitga'at Territory consists of small pleasure-craft vessels (<100 m), although shipments of bulk commodities and ferry vessels are common in summer months. Nearby boat sounds occurred mostly during June and July. For example, in June, 15 nearby boat sounds were identified in 310 recordings sampled (0.048 ± 0.0122). Nearby boats were identified to a lesser extent during. March–May and August–December. Distant boats were heard most often June–August. For example, in June, 9 distant boats were identified in 310 recordings (0.029 ± 0.0096). Aircraft were identified most often in June and July. In July, for example, 2 aircraft were identified in 143 recordings (0.014 ± 0.0099).

We included 'strong wave', 'strong wind' and 'strong rain' sounds as primary geophony (Fig. 9). Strong wave sounds occurred least often in April–June. Strong wave sounds were most prevalent in December where 174 strong wave events were heard in 1170 recordings sampled (0.1487 ± 0.0104). Strong winds were heard least often in June and July and most often in November where 118 strong wind events were heard in 960 recordings (0.123 ± 0.011). Strong rain was heard least often in July and was heard most often in September where 268 strong rain events were heard in 762 recordings (0.352 ± 0.017).

Sound identification (site specific): Fig. 10 shows the distribution of biophony, including the northern raven, bald eagle, sea gull species, winter wren, and Swainson's thrush that were identified in the soundscape at each site. The mean occurrence of these organisms was greatest at site HB07, about twice the amount of the other sites. Note that site HB07 is at the northern end of the proposed shipping channel (see Fig. 2).

Fig. 11 shows the distribution of technophony nearby and distance boats and aircraft based on identification of these entities at each of the eight sites. Site HB08 had the most technophony. This was likely due to the fact that HB08 is proximate

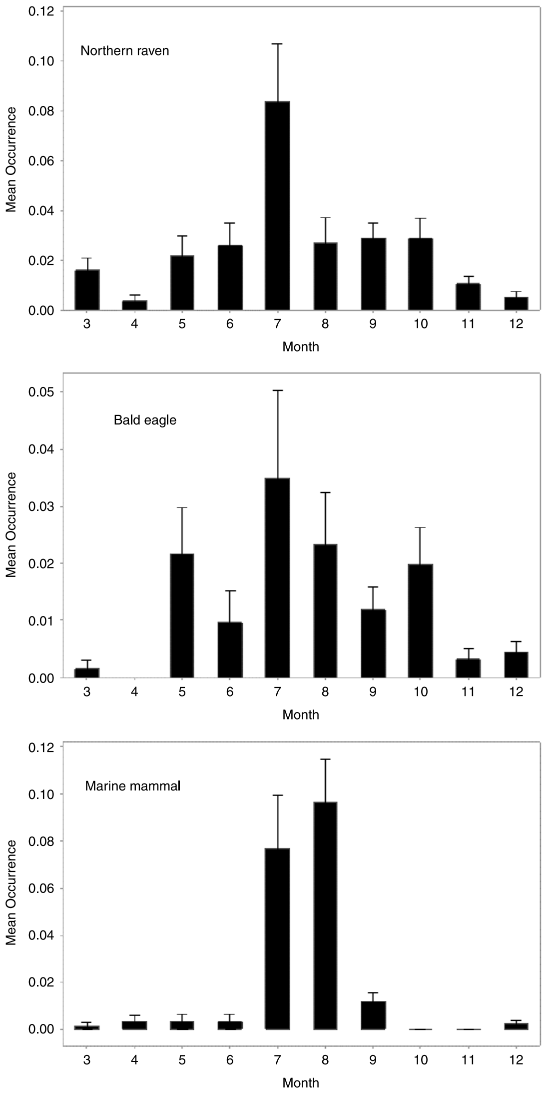

Fig. 7. Mean monthly occurrence (March–December) of primary biophony sounds.

to the ferry route on Grenville Channel as well as near to the Gitga'at village of Hartley Bay (thus increasing local incidences of boat traffic). However, site HB08 also had the second highest biophony sounds indicating a richness in local ecological attributes.

5. Discussion

Soundscape power patterns (see Fig. 3) show that in frequencies >F1–2 kHz, the dawn chorus is well underway by 0600 h. It then decreases during the daytime and subsequently increases at 1800 h, indicating the presence of dusk chorus. The low frequency interval (F1–2 kHz), defined as technophony, is reciprocal to the higher frequencies. Soundscape power in this low frequency interval declines during the dawn chorus, and then power in the low frequency interval increases steadily during the day, then declines again at 1800 h, at the same time as the dusk chorus. These patterns appear to be a common phenomenon, and were also observed in the 4-year study of the soundscape on a lake in northern Michigan (see Gage and Axel, 2013, Fig. 4).

The normalized difference soundscape index (NDSI), shown in Fig. 4, was used to summarize this large dataset (257 327) simultaneously over day of year and time of day. From this ratio of biophony and technophony, we show that most biophony occurs between days 150 and 250 between 0400 and 1200 h. The period of biological vulnerability also extends throughout the day between days 225 and 250. This information can be used as a management tool to avoid disruption of biophony. Note that the NDSI values in this sea–land interface are generally lower than those in more inland habitats (see Gage and Axel, 2013, Fig. 10), but the pattern is remarkably similar.

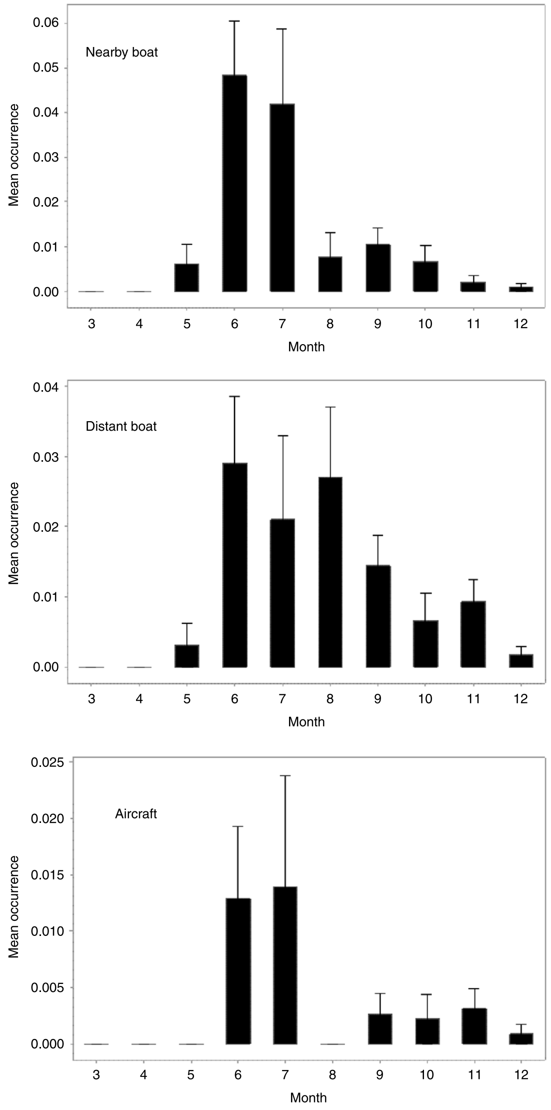

Fig. 8. Mean monthly occurrence (March–December) of nearby and distant boats and aircraft sounds.

June and July represent the period when waves, wind, and rain were lowest (Fig. 9) but this period was when we heard the most ravens, eagles and sea mammals (Fig. 7) and this also was the period where much of the technophony occurred (see Fig. 8). Also note the correspondence in August of the sounds of distant boats and sea mammals.

Site HB07 had the greatest biophony signal and was the site at the northwest end of the proposed shipping channel (see Figs. 2 and 10). The greatest amount of technophony was heard at HB08, the site located near the current ferry transportation corridor (see Figs. 2 and 11).

The 257 327 recordings collected between June 2013 and June 2014 are an affirmation of the uniqueness of Gitga'at Territory. Our findings demonstrate significant temporal and spatial distinctions in the relationships between time of day, seasonality, geophony and the distribution of avian communities and describe a heterogeneous acoustic environment at temporal scales (daily, monthly, seasonally, and annually). We also find that different sites across the Gitga'at Territory reflect important regional distinctions in anthropogenic activity (compare HB08 and HB04). The potential increase in boat traffic due to the establishment of a new shipping channel through the Gitga'at Territory will likely cause significant disturbance of the biophony in the region. It will be imperative to continue to record the soundscape at key times and key places in the Territory to evaluate emergent changes in the soundscape.

This baseline not only represents the rhythms of nature in Gitga'at Territory, but a basis for new intra-cultural dialogues about the ecological importance of sound. Following Corburn (2005), we have sought to reflect upon our methodological principles throughout this effort, and to expand the basis for the inclusion of local knowledge wherever possible. Penone et al. (2013) suggest that research rooted in sonic analysis is well suited to Citizen Science projects, owing to the reliability

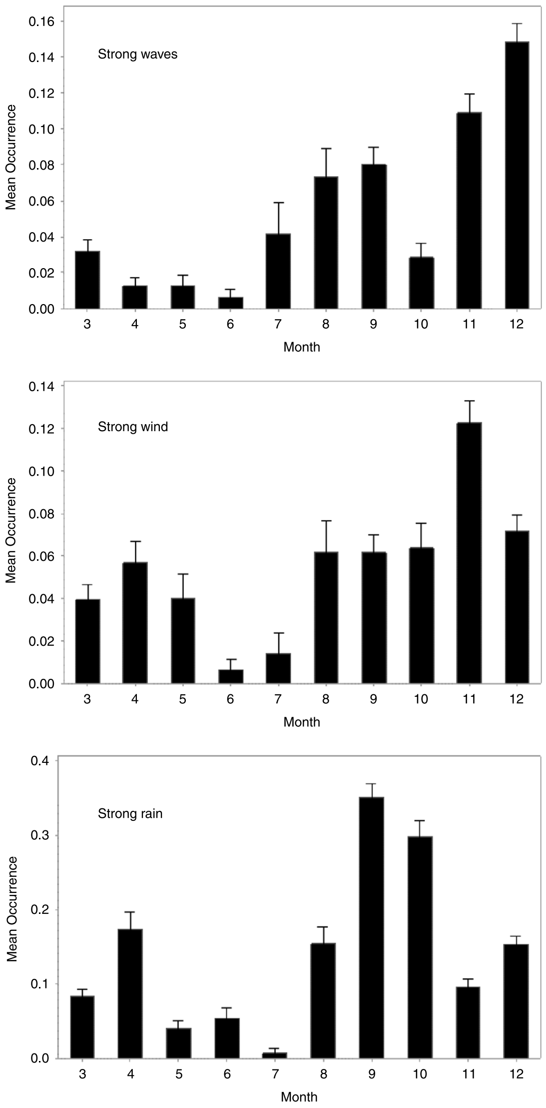

Fig. 9. Mean monthly occurrence (March–December) of geophony sounds including strong waves, strong wind and rain.

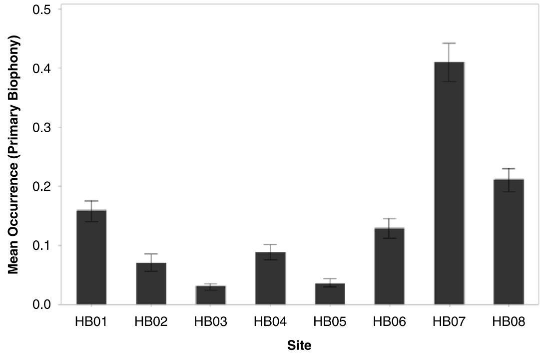

Fig. 10. Mean occurrence of primary biophony for each of the eight sites.

of sonic signals for classification and the relative operating ease of new data acquisition technologies. Hatch and Fristrup (2009) argue that effective noise control policies can only develop if the relevant transportation and resource management agencies are willing to surmount differences in their missions, professional cultures, and historical precedents. Our results

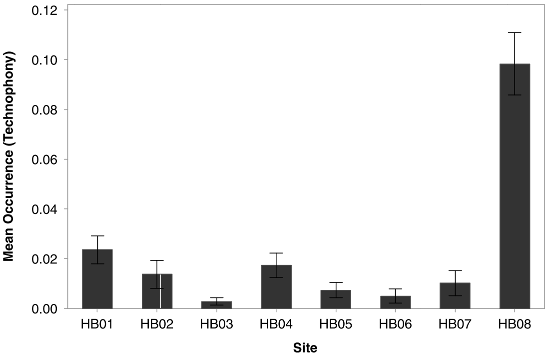

Fig. 11. Mean occurrence of technophony for each of the eight sites.

concur with both of these findings, adding the proviso that any scientific collaborations involving indigenous communities must constantly ensure the research is addressing the needs of the communities. Through our division of labor, we sought to counteract scholarly tendencies to bifurcate between 'expert' and 'non-expert' moments of analysis. We heeded the advice of Gitga'at Guardians for species-verification, and additionally note that a considerable amount of ecological knowledge of Gitga'at Territory has been generated through community solicitation (e.g. Turner and Clifton, 2009; Turner et al., 2012). Guardian-based species-identifications were later corroborated with our own analyses and a local birding authority (Dr. Reto Riesen) at Northwestern Community College (NWCC) in Prince Rupert, BC. In the cases where disagreements of identification arose, we consulted on-line databases and submitted received spectrograms to visual analysis to determine our results. Finally, to enable repeatability of the monitoring of the soundscape in Gitga'at Territory, we made considerable effort to maintain our recordings. All the recordings are archived within the REAL website (Kasten et al., 2012) and the sounds we collected as part of this study can be retrieved based on time and location query so they can be listened to for entity identification or reanalyzed when new methods become available.

Long term monitoring in Gitga'at Territory is challenging due to inclement weather, high fuel costs, and community priorities (Ashe et al., 2013). While engaging with busy local community does present challenges, these are far outweighed by the benefits. We were not only granted access to an important study-area (socially and ecologically) but were provided with vessel support, local advice and technical assistance throughout this project. Key determinants of the study, including selection of site locations, identification of indicator species, and visits to sites for data acquisition and sensor management, were only made possible by collaboration. More fine-grained analysis is needed to understand inter-species interactions across different study-sites, as well as to attend to the effects of geophonic sounds (e.g. wind) on biophonic patterns (Pijanowski et al., 2011). Sound is a valuable but imperfect tool for ecological analysis. Not only are there wide differences in the degree to which species vocalize, but insofar as soundscape ecology relies on human listening practitioners, it suffers anthropocentric bias. Our baseline undervalues very low and very high frequency sounds, and fails to identify vocalizations masked by heavy rainfall or wind. It is limited by a sampling period that was biased toward easily perceptible avian communities.

Our acoustic baseline is an initial 'coarse-grain' effort to document the rich and extremely unique socio-ecological relationships of Gitga'at Territory. We contend that our approach presents a viable model for indigenous-led science collaboration, repeatable in other contexts to the extent that local differences and community needs are similarly engaged (Adams et al., 2014). New efforts are underway to automatically identify species in soundscape ecology and we recognize that baseline monitoring will become even more useful to Gitga'at when these advances are fulfilled. Additional work at the intersection of "Street Science", soundscape ecology, and indigenous-led science collaboration would be of benefit to many.

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Foremost, we wish to thank the Gitga'at Nation for the privilege of conducting research with them. It is our sincere hope that this work will contribute in some way to their stewardship of Gitga'at Territory. The Gitga'at Guardians were a major contributor to the success of this effort; many thanks to Matt Danes, Myron Dundas, Marven Robinson, Robin Robinson, and Donald Reece for their assistance. Thanks as well to Spencer Greening and Tianna Robinson for generously sharing traditional place name information and Kim-Ly Thompson and Reto Riesen for their support. We wish to thank the Willow Grove foundation for provided partial funding for this project, and in particular Andy Wright for his generosity, vision, and commitment to conservation up and down the North Coast. We also wish to thank Ralph and Sharon Turfus for their generous support, and Janie Wray for advice throughout the early stages of this project. We also acknowledge the helpful comments and suggestions by anonymous reviewers who made a significant contribution to this paper.

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