



Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: [www.elsevier.com/locate/jglr](http://www.elsevier.com/locate/jglr)

## Song of the burbot: Under-ice acoustic signaling by a freshwater gadoid fish

Peter A. Cott<sup>a,b,\*</sup>, Anthony D. Hawkins<sup>c,1</sup>, David Zeddies<sup>d,2</sup>, Bruce Martin<sup>d,2</sup>, Thomas A. Johnston<sup>b,e,3</sup>, James D. Reist<sup>f,4</sup>, John M. Gunn<sup>b,5</sup>, Dennis M. Higgs<sup>g,6</sup>

<sup>a</sup> Department of Fisheries and Oceans, #301, 5205-50th Ave., Yellowknife, Northwest Territories X1A 1E2, Canada

<sup>b</sup> Laurentian University, Vale Living With Lakes Centre, Cooperative Freshwater Ecology Unit, 935 Ramsey Lake Road, Sudbury, Ontario P3E 2C6, Canada

<sup>c</sup> Loughine Ltd, Kincaig, Blairs, Aberdeen AB12 5YT, Scotland, UK

<sup>d</sup> JASCO Applied Sciences, Suite 202 Troop Ave, Dartmouth, NS B3B 1Z1, Canada

<sup>e</sup> Ontario Ministry of Natural Resources, 935 Ramsey Lake Road, Sudbury, Ontario P3E 2C6, Canada

<sup>f</sup> Department of Fisheries and Oceans, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada

<sup>g</sup> Department of Biological Sciences, University of Windsor, 401 Sunset Avenue, Windsor, Ontario N9B 3P4, Canada

### ARTICLE INFO

#### Article history:

Received 18 October 2013

Accepted 10 February 2014

Available online xxxx

Communicated by Thomas Hrabik

#### Index words:

Burbot

Fish calls

Gadidae

*Lota lota*

Reproduction

Spawning Great Slave Lake

### ABSTRACT

Burbot (*Lota lota*) are northern freshwater gadoid fish that spawn under ice-cover, making their reproductive behavior largely unknown to science. Some members of the cod family vocalize as part of their mating system. These calls are produced by rapidly contracting drumming muscles on their swim bladders. Burbot also possess drumming muscles, like their marine counterparts, which may enable them to vocalize. To assess the potential for burbot to make calls, pre-spawning adult burbot were collected and placed in a large under-ice enclosure in Great Slave Lake, Northwest Territories, Canada, along with a recorder that monitored low frequency sound over their spawning period. The recorded acoustic data revealed that burbot called coincident with the onset of their spawning period and that the call signatures were stereotypical of swim bladder generated vocalizations made by other gadoid fishes. Burbot showed a wide repertoire of calls, from slow knocks to fast buzzing, similar to the closely related haddock (*Melanogrammus aeglefinus*). Although never-before documented, calling by fish under ice-cover is likely an important part of the mating system of under-ice spawning gadoids because light limitation would reduce the usefulness of visual cues. These under-ice communications may be affected by anthropogenic noise from increasing resource development in northern regions.

© 2014 International Association for Great Lakes Research. Published by Elsevier B.V. All rights reserved.

### Introduction

Some fishes in the commercially important family Gadidae, the cod fishes (Cohen et al., 1990), produce sounds during their reproductive period (Hawkins, 1993; Kasumyan, 2009). These sounds are typically produced by rapidly contracting striated muscles (drumming muscles) located dorso-laterally on the swim bladder (Hawkins and Amarin, 2000; Parmentier et al., 2006). Atlantic cod (*Gadus morhua*), produce simple, stereotyped calls that are limited to low frequency grunts

(Brawn, 1961; Hawkins and Rasmussen, 1978; Rowe and Hutchings, 2006) or hums (Rowe and Hutchings, 2006), while haddock (*Melanogrammus aeglefinus*) produce a complex mixture of grunts, knocks, hums, and buzzes (Hawkins and Amarin, 2000; Hawkins and Rasmussen, 1978). Although not all cod fish species that possess drumming muscles vocalize (Hawkins and Rasmussen, 1978), it is clear that the presence of such muscles represents the potential for vocal ability.

Burbot (*Lota lota*) are the only freshwater gadoid (Cohen et al., 1990) and one of the most widely distributed freshwater fish species in the world (Van Houdt et al., 2005). However, little is known about the reproductive ecology of burbot (McPhail and Paragamian, 2000), largely because they spawn in mid-winter, under ice-cover (McPhail and Paragamian, 2000; Scott and Crossman, 1973). The limited light during their reproductive period, their relatively sensitive hearing (Cott et al., 2013a), the presence of drumming muscles, and the fact that their drumming muscle mass increases towards the spawning season (Cott et al., 2013b,c) suggest that sound production and reception could play a primary role for burbot in communicating mating cues.

We hypothesized that burbot vocalize in association with their reproduction as is the case in certain other members of the cod family that possess swim bladder muscles (Hawkins and Rasmussen, 1978;

\* Corresponding author at: Wilfrid Laurier University, WLU-GNWT Partnership, Box 1591, Yellowknife, NT X1A 2P2, Canada. Tel.: +1 867 444 9345.

E-mail addresses: [pcott@wlu.ca](mailto:pcott@wlu.ca) (P.A. Cott), [a.hawkins@btconnect.com](mailto:a.hawkins@btconnect.com) (A.D. Hawkins), [david.zeddies@jasco.com](mailto:david.zeddies@jasco.com) (D. Zeddies), [Bruce.Martin@jasco.com](mailto:Bruce.Martin@jasco.com) (B. Martin), [tjohnston@laurentian.ca](mailto:tjohnston@laurentian.ca) (T.A. Johnston), [jim.reist@dfo-mpo.gc.ca](mailto:jim.reist@dfo-mpo.gc.ca) (J.D. Reist), [jgunn@laurentian.ca](mailto:jgunn@laurentian.ca) (J.M. Gunn), [dhiggs@uwindsor.ca](mailto:dhiggs@uwindsor.ca) (D.M. Higgs).

<sup>1</sup> Tel.: +44 1224 868984.

<sup>2</sup> Tel.: +1 902 405 3336.

<sup>3</sup> Tel.: +1 705 671 3828.

<sup>4</sup> Tel.: +1 204 983 5032.

<sup>5</sup> Tel.: +1 705 675 4831.

<sup>6</sup> Tel.: +1 519 253 3000.

Rowe and Hutchings, 2006, 2008). We predicted that burbot calls would be similar to those of other vocal gadoids and that calls would occur at the onset of spawning, possibly to signal reproductive readiness. To test this prediction, we monitored wild burbot in an experimental enclosure in a northern lake over the expected spawning period using an underwater sound recorder. We selected a study location within the core range of burbot where environmental conditions would be typical for this species (Cott et al., 2013b).

## Materials and methods

In Canada, burbot typically spawn between January and March, in shallow water (0–10 m), over a variety of substrates from silt and sand to coarse gravel and cobble (McPhail, 2007; McPhail and Paragamian, 2000; Scott and Crossman, 1973). A 10 m × 10 m × 10 m experimental enclosure (hereafter the Lota-tron) was suspended under the ice in Yellowknife Bay, Great Slave Lake near the City of Yellowknife, Northwest Territories, Canada (62°26′30″ N 114°20′70″ W; Fig. 1). The Lota-tron was constructed entirely of 1-in. nylon mesh that allowed for free mixing of the surrounding lake water. Because nylon mesh has a specific gravity almost identical to water it is acoustically transparent when wet. The Lota-tron was deployed through the ice on December 8, 2009, prior to the expected spawning period and positioned in a mean water depth of 9.5 m over a firm sandy-silt substrate intermixed with gravel and cobble. This allowed the mesh bottom to rest directly on the substrate, emulating natural spawning habitat. The bottom was anchored in place using concrete blocks, with the top corners pulled tight and anchored in place above the ice with ice-screws. The top edge of each wall was equipped with floats allowing the ice to

freeze the tops of the walls in place with the ice serving as a lid, forming a 900 m<sup>3</sup> enclosure. The ice at the study location was approximately 50 cm thick in December, attaining a maximum thickness of 110 cm by the conclusion of the study. With snow and ice cover, light penetration at 9 m depth is below the detection limit of our light sensing equipment, i.e., <10.8 lm/m<sup>2</sup> (M. Guzzo, P. Blanchfield, P. Cott, unpublished data).

An automated multi-channel acoustic recorder (AMAR; JASCO Applied Sciences, Victoria, BC, Canada) was suspended in the center of the Lota-tron, 1 m above the lake bottom. An M15B hydrophone (GeoSpectrum Technologies Inc., Dartmouth, NS, Canada) with a sensitivity of –160 dBV/μPa was fitted to the AMAR. A continuous recording was collected at a sampling rate of 16 kps. This configuration had a broadband noise floor of 81 dB re 1 μPa and a spectral noise floor of 42 dB re 1 μPa<sup>2</sup>/Hz at 100 Hz. The AMAR continuously recorded from December 15, 2009 until retrieval on March 6, 2010, spanning the expected spawning period for this burbot population.

A total of 31 burbot were collected from Yellowknife Bay in close proximity to the Lota-tron, using a combination of baited long lines and gillnets as per Cott et al. (2011); all fishing gear was set in water depths less than 10 m to minimize barotrauma (Bruesewitz et al., 1993). Thirteen of the captured burbot were placed in the Lota-tron from December 19, 2009 to January 13, 2010, and the remaining 18 were collected and added in the period from February 9 to February 18, 2010. Burbot in the Lota-tron were fed weekly with cut-up cisco (*Coregonus artedii*). During the collection of burbot for use in the Lota-tron, fish that were incidentally injured were used for a concurrent study on the reproductive ecology of burbot (Cott et al., 2013b). From the concurrent reproductive ecology study (Cott et al., 2013b), burbot

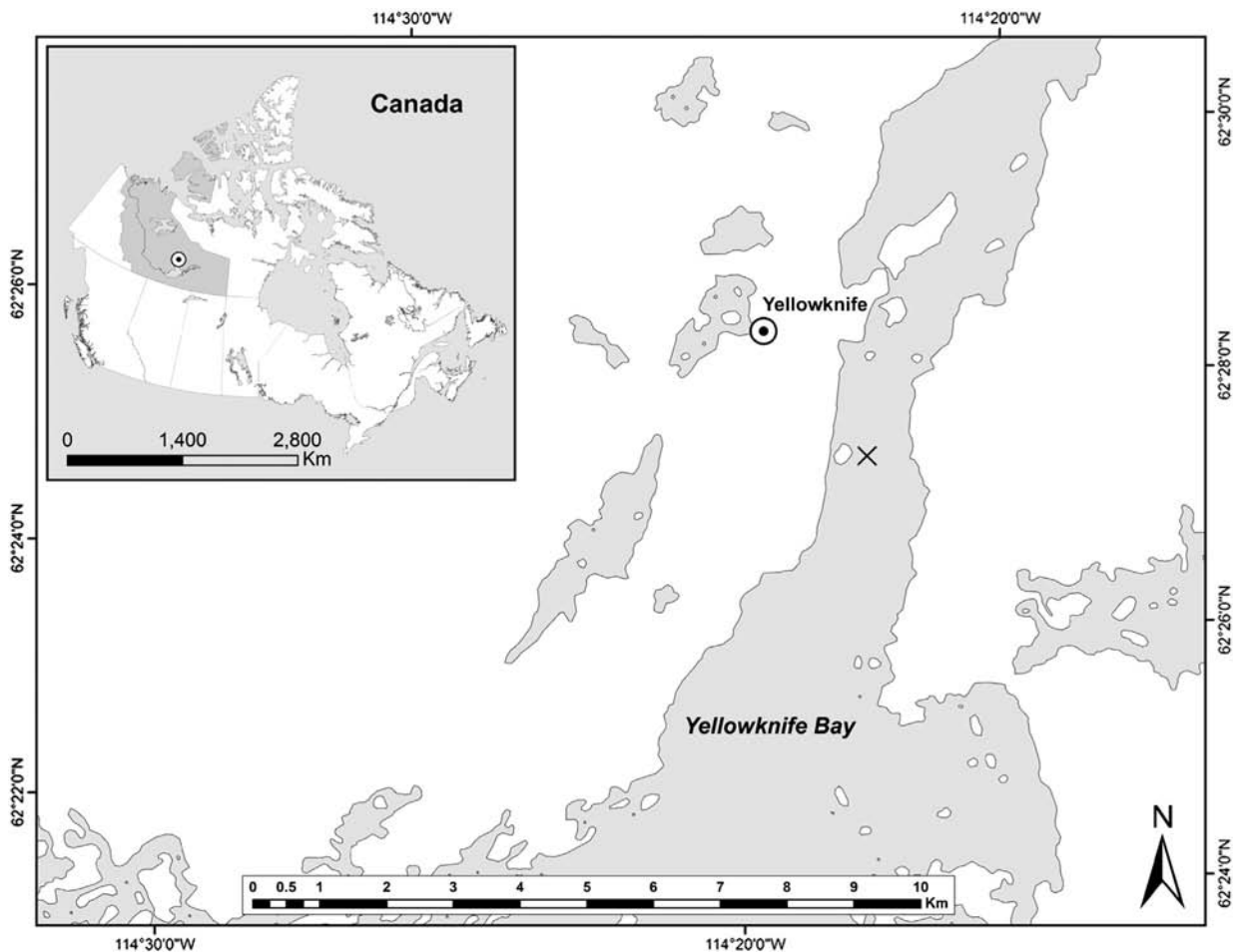


Fig. 1. Location of the burbot enclosure (Lota-tron) (denoted by the “X”) in Yellowknife Bay, Great Slave Lake, Northwest Territories, Canada.

in Yellowknife Bay were determined to be in spawning condition for a 3-week period beginning at the start of February. The ratio of reproductively mature females to adult females that were not in spawning condition was 1.1 to 1.

Post-processing of acoustic data used a combination of manual and automated detections. The spectral density as a function of time (spectrogram) was obtained for the entirety of the recording duration. Where the spectrogram indicated periods of increased acoustic energy, manual analysis—listening to the recordings and viewing the waveforms and spectra—was performed both for samples with increased acoustic energy and for those with lower acoustic energy. The initial manual analysis identified dominant sound sources, primarily from cracking ice (but also noise from snow machines, ice-road traffic, and air traffic) and their characteristics, such as frequency content and duration, using data from Mann et al. (2009). For sounds identified of biological origin, presumed to be burbot based on comparisons to recordings of Atlantic cod vocalizations (S. Rowe, Memorial University pers. comm.), automated zero-crossing detector software was used. A zero-crossing (time-domain waveform going from a positive value to negative or vice versa) of longer than 0.005 s and shorter than 0.3 s (and exceeding a minimum voltage) detected vocalizations while rejecting typical ice-cracking events and anthropogenic noise. Follow-up manual analysis was used to spot-check detected events. To determine the source level from the received level, transmission loss was taken into account. With the recorder centered at the bottom of the Lota-tron, suspended 1 m off the substrate, the mean distance from the edge of the Lota-tron to the recorder was 5.48 m. Spherical spreading ( $20 * \log(r)$ ) was used to correct for transmission loss, and 14.78 dB was added to the received level to obtain source levels.

## Results and discussion

Burbot calls were detected from within the Lota-tron. Spectrograms and band-level plots showed variations in recorded acoustic energy as a function of time and frequency, indicating periods of increased sound energy of low frequency (< 100 Hz) from late January to mid-March. Much of this low frequency sound energy occurred during a brief intense event on February 1 and 2, 2010 (Fig. 2), coincident with the onset of spawning for Yellowknife Bay burbot. Because the sounds

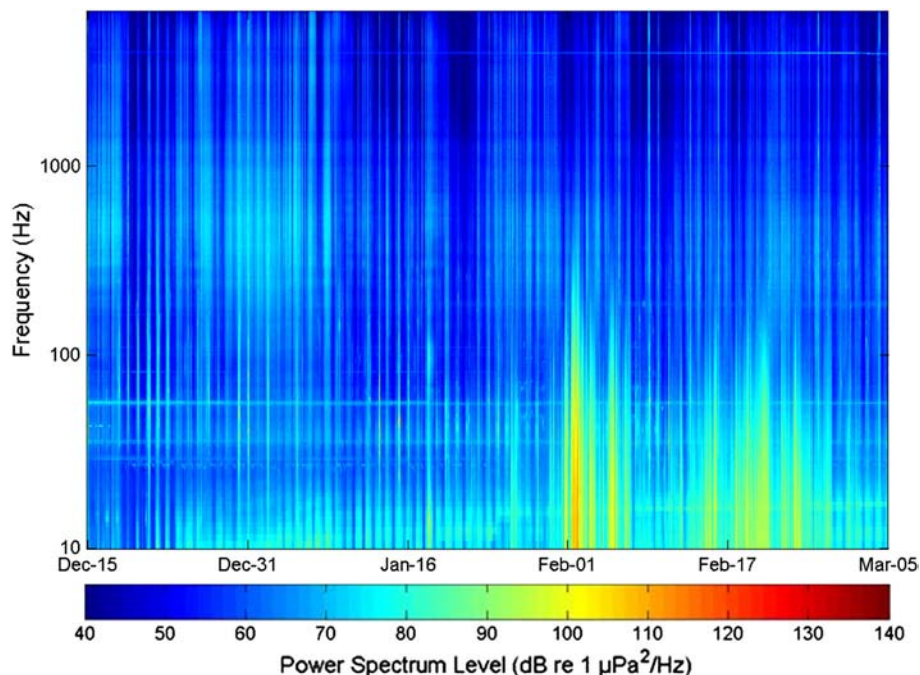


Fig. 2. Sound energy recorded within an experimental enclosure in Yellowknife Bay, Great Slave Lake, Northwest Territories, Canada, from December 15, 2009, to March 6, 2010.

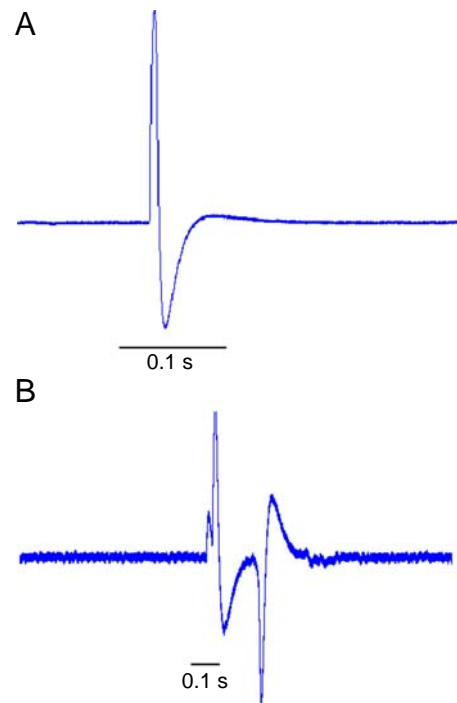


Fig. 3. The base unit of a burbot call is a biphasic pulse (expressed as sound pressure over time) which can occur A) single or B) double, with the second pulse inverted in phase from the first. This sound signature is stereotypical of a swim bladder generated call.

were atypical of ice or anthropogenic noise and their double-pulse sound signature was virtually identical to those reported from other vocalizing gadoid fishes, these sounds were ascribed to the burbot.

It was determined through transmission loss calculations that the burbot calls originated within the Lota-tron. Burbot are known to show a high affinity for structure and each other (Edsall et al., 1993), and during the spawning period can be found in writhing balls composed of many individuals (Cahn, 1936; McPhail and Paragamian, 2000). Given that it was the spawning period and cinderblocks anchoring the AMAR

recorder were the only form of structure, it is unlikely that the burbot within the Lota-tron were randomly distributed. If the burbot congregated near the anchor structure, which was likely, they would have been approximately 1 m from the recorder and no transmission loss correction would need to be applied. Based on these assumptions, the source levels of burbot vocalizations recorded on February 1 and 2 were estimated between  $131 \pm 2.6$  (SD) and  $135 \pm 2.3$  (SD) dB re  $1 \mu\text{Pa}$  rms SPL.

The basic unit of sound production was a stereotyped biphasic pulse (Fig. 3A), often isolated with no other pulse preceding or following within a few seconds. Double pulses were also common, with two of the stereotyped pulses closely spaced ( $< 1$  s), and the second pulse typically inverted in phase from the first (Fig. 3B). These biphasic pulses are characteristic of sounds made with a gas-filled swim bladder, such as those of haddock (Hawkins and Amorin, 2000). Continuous sequences of these pulses were recorded, ranging from a few seconds to approximately 1 min. Time between pulse sequences for individual fish could not be determined because multiple burbot called at the same time and these calls often overlapped. Regularly repeated biphasic pulse sequences resulted in knock-like calls (Hawkins and Amorin, 2000) (Fig. 4A) which sounded like a drum beat. Shortening the inter-pulse interval of the pulse sequence by burbot resulted in calls that sounded like a revving engine (Fig. 4B and C). In some cases the inter-pulse interval was modulated throughout the call (Fig. 4D). Complex longer duration, buzz-like calls with frequency modulation and sustained periods of low inter-pulse intervals were also recorded (Fig. 5). In these complex calls,

the higher-frequency proportions consisted of nearly sinusoidal waveforms (Fig. 5) of up to 500 Hz.

Burbot calls were strikingly similar to haddock calls. For example, the call signature shown in Fig. 4A is similar to a male haddock calling alone, whereas the calls shown in Fig. 4B–D are akin to calls made by a male haddock when a female or rival male approached (Hawkins and Amorin, 2000). In Electronic Supplementary material ESM two sound files are provided which give examples of typical burbot and haddock calls. The burbot calls in the ESM were recorded from within the Lota-tron during the present study; while the haddock calls were recorded in a laboratory when direct spawning behavior associated with vocalizations was observed during a study conducted by Hawkins and Amorin (2000).

Although observations of spawning behavior were not part of this study, as seen in Fig. 2, the bulk of the calls occurred at the initiation of the reproductive period for the population investigated, suggesting that burbot sound production is related to their reproduction. Increases in drumming muscle mass with the onset of reproduction have been shown for Atlantic cod (Nordeide et al., 2008; Rowe and Hutchings, 2008), and have been linked to mate selection (Hutchings et al., 1999; Rowe and Hutchings, 2006, 2008), and mating success, with males that had larger drumming muscles being more attractive to females, presumably because of enhanced vocalization (Rowe and Hutchings, 2008). Burbot drumming muscles are fused to their swim bladders; and, like Atlantic cod, burbot swim bladder mass also increases towards

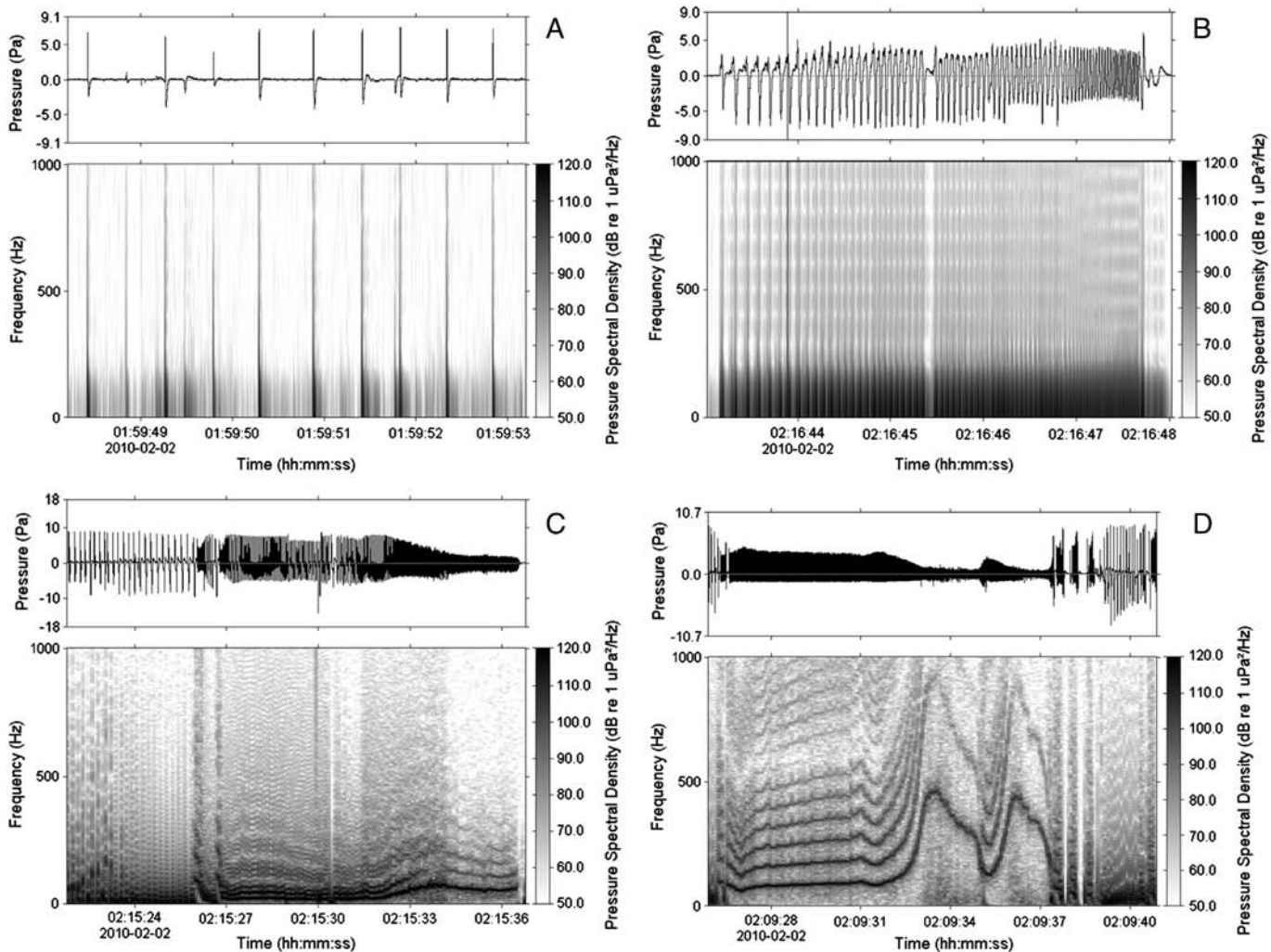
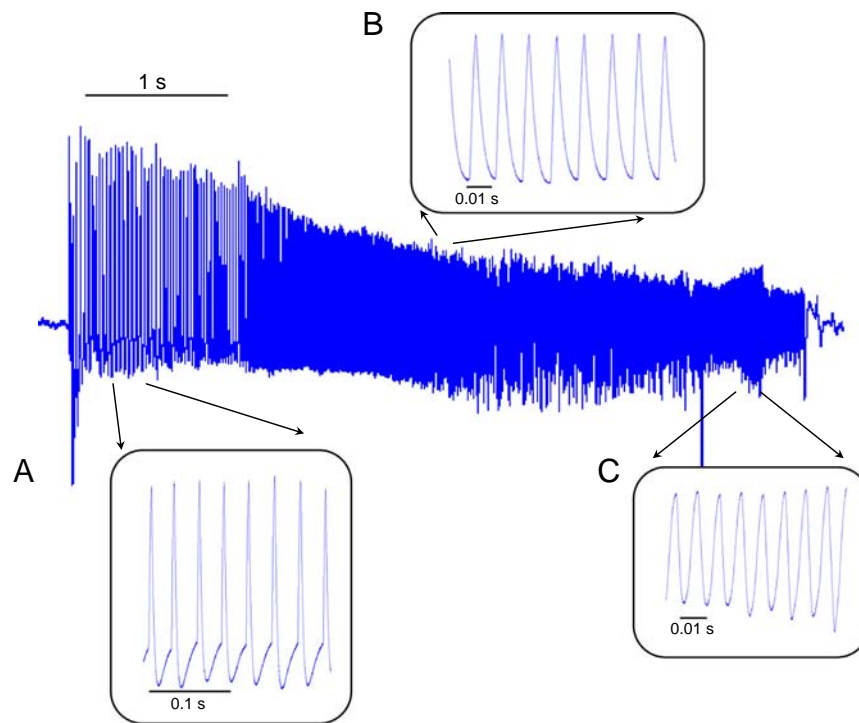


Fig. 4. A variety of burbot vocalizations, including (A) slow knocks, (B) slow knocks with frequency upsweep, (C) slow knocks increasing in pulse speed and changing to a hum, and (D) a complex hum call. Spectrograms for (A) and (B) 1 Hz resolution, 0.01 s of data, 0.001 s advance, Hanning window. Spectrograms for (C) and (D) 1 Hz resolution, 0.187 s of data, 0.0625 s advance, Hanning window.



**Fig. 5.** A burbot call, made up of a variety of different pulse types: A) low frequency, B) mid-frequency, and C) nearly sinusoidal high frequency. Calls expressed as sound pressure over time.

the spawning period with males having heavier swim bladders than females (Cott et al., 2013c). This again suggests that drumming muscles are used in reproduction and that males may vocalize more than females. It is possible that burbot vocalize at other times of the year and for reasons other than reproduction, but it is likely that vocalizations are most important in the light-limited under-ice spawning environment. Other gadoids use vocalizations to synchronize spawning and elicit gamete release (Hawkins, 1993), particularly at depths where ambient light is limited.

Ice cover results in a lack of wave and storm noise, so natural background noise is minimal when burbot reproduce, e.g. a typical 1-min period measured  $96.5 \pm 5.1$  (SD) dB re  $1 \mu\text{Pa}$  rms SPL over the frequency range 10 to 8000 Hz (Mann et al., 2009). Northern resource development activities, such as exploratory drilling, are often conducted during winter over frozen lakes and rivers because at this time of year ice roads can be built to access otherwise inaccessible areas (Cott et al., 2008; Mann et al., 2009). These activities generate persistent sounds that alter the soundscapes of under-ice environments (Mann et al., 2009). Cracking ice is distinctive and the only form of natural noise; and, although transient, cracking ice can be loud with peak pressure levels often exceeding the recorder's saturation limit of 161 dB re  $1 \mu\text{Pa}$  (Mann et al., 2009). Persistent anthropogenic noises above normal ambient levels can raise hearing detection thresholds of animals, thereby masking their communication sounds (Hawkins and Chapman, 1975) and have been shown to disrupt spawning vocalizations and behavior of Atlantic cod (Finstad and Nordeide, 2004). Therefore anthropogenic noise could theoretically interfere with the acoustic signaling of under-ice spawning gadoid fishes such as burbot, Arctic cod (*Boreogadus saida*), and Greenland cod (*Gadus ogac*). The latter two species of marine gadoids possess drumming muscles (Hawkins and Rasmussen, 1978), and may also use acoustic signaling for attracting mates or signaling reproduction.

## Conclusions

Burbot vocalizations are similar to those of other closely related marine gadoids. The ability to vocalize is a useful adaptation for

communicating in low light environments and is likely a holdover from their marine ancestry. Although monitoring of burbot vocalizations was conducted over a 2.5-month period, the peak of calling corresponded with the onset of spawning. The timing of burbot calls as well as the fact that swim bladder mass was highest at the spawning period (Cott et al., 2013c), strongly suggest that burbot vocalizations are likely part of their mating system, similar to other cod fishes. This finding opens the way for future researchers to investigate questions such as determining the detection distance of burbot calls, determining the potential for seasonality of vocalizations, and documenting behaviors associated with sound production. This is the first study to document acoustic signaling of fish under ice-cover, and underscores how little we know about the winter ecology of fishes. Acoustic monitoring of vocalizations represents an important new approach for detecting fish and assessing reproduction where conventional methods may be logistically difficult. Although unlikely to be an issue for the burbot of Yellowknife Bay, disruption to the reproductive success of winter spawning gadoid species, as a result of anthropogenic changes to their under-ice soundscapes, could have negative effects on sensitive Arctic and sub-Arctic ecosystems.

## Acknowledgements

Field assistance was provided by R. Walbourne, B. Hanna, S. Elsasser and other staff from Fisheries and Oceans Canada and JASCO Applied Sciences. Thanks to J. Hutchings, S. Rowe, and G. Crozier for their review of earlier drafts of this manuscript, and M. McPherson, B. Hanna, S. Stephenson, E. Szkokan-Emilson, and N. Mochnac for their review of later drafts. Thanks to S. Rowe for providing an Atlantic cod recording to enable calibration of recording equipment. Thanks to D. Mann for his ideas regarding the initial study concept, and A. Popper for his continued advice and guidance on bioacoustics to PC. This study was conducted as per the Freshwater Institute Science Laboratories Animal Care Committee Protocol #FWI-ACC-2009-066. Funding for this project was made available through Natural Resources Canada's Program for Energy Research and Development, and the Department of Fisheries and Oceans – Western Arctic Area.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.jglr.2014.02.017>.

## References

- Brawn, V.M., 1961. Sound production by the cod (*Gadus callarias* L.). Behaviour 18, 239–255.
- Bruesewitz, R.E., Coble, D.W., Copes, F., 1993. Effects of deflating the expanded swim bladder on survival of burbot. North Am. J. Fish. Manag. 13, 346–348.
- Cahn, A.R., 1936. Observations on the breeding of the lawyer, *Lota maculosa*. Copeia 3, 136–165.
- Cohen, D.M., Inada, T., Iwamoto, T., Scialabba, N., 1990. FAO Species Catalogue. v. 10: Gadiform Fishes of the World (Order Gadiformes). FAO, Rome.
- Cott, P.A., Sibley, P., Gordon, A., Bodaly, R.A., Mills, K., Somers, M., Fillatre, G., 2008. The effects of water withdrawal from ice-covered lakes on oxygen, temperature and fish. J. Am. Water Res. Assoc. 44, 328–342.
- Cott, P.A., Johnston, T.A., Gunn, J.M., 2011. Food web position of burbot relative to lake trout, northern pike, and lake whitefish in four sub-Arctic boreal lakes. J. Appl. Ichthyol. 27, 49–56.
- Cott, P.A., Johnston, T.A., Gunn, J.M., Higgs, D.M., 2013a. Hearing sensitivity of the burbot. Trans. Am. Fish. Soc. 142, 1699–1704.
- Cott, P.A., Johnston, T.A., Gunn, J.M., 2013b. Stability in life history characteristics among burbot populations across environmental gradients. Trans. Am. Fish. Soc. 142, 1746–1756.
- Cott, P.A., Johnston, T.A., Gunn, J.M., 2013c. Sexual dimorphism in an under-ice spawning fish: the burbot (*Lota lota*). Can. J. Zool. 91, 732–740.
- Edsall, T.A., Kennedy, G.W., Horns, W.H., 1993. Distribution, abundance, and resting microhabitat of burbot on Julian's Reef, southwestern Lake Michigan. Trans. Am. Fish. Soc. 122, 560–574.
- Finstad, J.L., Nordeide, J.T., 2004. Acoustic repertoire of spawning cod, *Gadus morhua*. Environ. Biol. Fish 70, 427–433.
- Hawkins, A.D., 1993. Underwater sound and fish behaviour. In: Picther, T. (Ed.), Behaviour of Teleost Fishes. Chapman & Hall, London, U.K., pp. 129–169.
- Hawkins, A.D., Amorin, M.C., 2000. Spawning sounds of the male haddock, *Melanogrammus aeglefinus*. Environ. Biol. Fish 59, 29–41.
- Hawkins, A.D., Chapman, C.J., 1975. Masked auditory thresholds in the cod (*Gadus morhua* L.). J. Comp. Physiol. A 103, 209–226.
- Hawkins, A.D., Rasmussen, K.J., 1978. The calls of gadoid fish. J. Mar. Biol. Assoc. U. K. 58, 891–911.
- Hutchings, J.A., Bishop, T.D., McGregor-Shaw, C.R., 1999. Spawning behaviour of Atlantic cod, *Gadus morhua*: evidence of mate competition and mate choice in a broadcast spawner. Can. J. Fish. Aquat. Sci. 56, 97–104.
- Kasumyan, A.O., 2009. Acoustic signaling in fish. J. Ichthyol. 49, 963–1020.
- Mann, D., Cott, P.A., Horne, B., 2009. Under-ice noise generated from diamond exploration in a Canadian sub-arctic lake and potential impacts on fishes. J. Acoust. Soc. Am. 126, 2215–2222.
- McPhail, J.D., 2007. The Freshwater Fishes of British Columbia. The University of Alberta Press, Edmonton.
- McPhail, J.D., Paragamian, V.L., 2000. Burbot biology and life history. In: Paragamian, V.L., Willis, D.W. (Eds.), Burbot: Biology, Ecology, and Management. Fisheries Management Section of the American Fisheries Society, Spokane, Washington, pp. 11–23.
- Nordeide, J.T., Solberg, C., Willumsen, L., Amble, S.B., 2008. Seasonal variation and condition-dependence of the drumming muscle of cod, *Gadus morhua* L.? – An experimental approach. J. Exp. Marine Biol. Ecol. 363, 66–74.
- Parmentier, E., Lagardère, J.-P., Braquegnier, J.-B., Vandewalle, P., Fine, M.L., 2006. Sound production mechanism in a carapid fish: first example with a slow sonic muscle. J. Exp. Biol. 209, 2952–2960.
- Rowe, S., Hutchings, J.A., 2006. Sound production by Atlantic cod during spawning. Trans. Am. Fish. Soc. 135, 529–538.
- Rowe, S., Hutchings, J.A., 2008. A link between sound producing musculature and mating success in Atlantic cod. J. Fish Biol. 72, 500–511.
- Scott, W.B., Crossman, E.J., 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Ottawa.
- Van Houdt, J.K.J., de Cleyn, L., Perretti, A., Volckaert, F.A.M., 2005. A mitogenic view on the evolutionary history of the Holarctic freshwater gadoid, burbot (*Lota lota*). Mol. Ecol. 14, 2445–2457.