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This is a post-print version of the following article:

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April 2020

The final publication is available at:

<https://doi.org/10.1121/10.0001071>

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Citation for this paper:

Riera, A., Rountree, R. A., Agagnier, L., & Juanes, F. (2020). Sablefish (*Anoplopoma fimbria*) produce high frequency rasp sounds with frequency modulation. *The Journal of the Acoustical Society of America*, 147(4), 2295-2301. <https://doi.org/10.1121/10.0001071>.

# **Sablefish (*Anoplopoma fimbria*) produce high frequency rasp sounds with frequency modulation**

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(Submitted 5 December 2019)

**Running title:** Sablefish rasps

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1 **Abstract: (200 words max)**

2 Sablefish sounds, named rasps, were recorded at two captive facilities in British Columbia and  
3 Washington State. Rasps consisted of highly variable broadband trains of 2 to 336 ticks that  
4 lasted between 74 and 10,500 ms. The 260 rasps that were measured contained frequencies  
5 between 344 to 34,000 Hz with an average peak frequency of 3,409 Hz. The frequency structure  
6 of ticks within rasps was highly variable and included both positive and negative trends. This  
7 finding makes sablefish one of the few deep-sea fish for which sounds have been validated and  
8 described. The documentation of sablefish sounds will enable the use of passive acoustic  
9 monitoring methods in fisheries and ecological studies of this commercially important deep-sea  
10 fish.

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12

13 **Key words:** Sablefish, *Anoplopoma fimbria*, bioacoustics, fish sounds, fish behavior, soniferous fish,  
14 passive acoustic monitoring, deep-sea fish

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25 **I. INTRODUCTION**

26 Fish sounds have been studied since at least the late 1800s (Dufossé, 1874) and since then there  
27 have been numerous accounts of the variability that exists in fish sound production (Fish, 1948;  
28 Fish *et al.*, 1952; Moulton, 1963; Schneider, 1966; Tavalga, 1971; Hawkins, 1993; Kaatz, 2002;  
29 Ladich, 2004; Fine and Parmentier, 2015; Zeyl *et al.*, 2016). The ability to recognize fish sounds  
30 is becoming increasingly useful for passive acoustic monitoring (PAM) studies on population  
31 and ecosystem health (Rountree *et al.*, 2006; Slabbekoorn *et al.*, 2010; Riera *et al.*, 2016; Archer  
32 *et al.*, 2018; Lindseth and Lobel, 2018). In order to use PAM, examples of sounds from each  
33 species of fish need to be validated and available for comparison to the sounds recorded through  
34 PAM (Rountree *et al.*, 2002). There are currently ~34,300 known fish species (Froese and Pauly,  
35 2019) and sound production has been reported for fewer than 1000 species (Lobel *et al.*, 2010)  
36 although an updated number remains to be confirmed. This number is growing as new fish  
37 sounds are being described (Wilson *et al.*, 2004; Riera *et al.*, 2018; Rountree *et al.*, 2018).  
38 Despite these efforts, the capacity for sound production remains to be investigated for the  
39 majority of fish species (Rountree *et al.*, 2002; Rountree *et al.*, 2019).

40 There is increasing interest in understanding the dynamics and health of deep-sea ecosystems  
41 such as sponge reefs (Archer *et al.*, 2018), seamounts (Department of Fisheries and Oceans  
42 Canada, 2011) and banks, as these systems are fragile and vulnerable to overfishing (Koslow *et*  
43 *al.*, 2000). The soundscape of the deep sea is poorly known and the use of PAM methods to  
44 study these ecosystems is becoming more common (Rountree *et al.*, 2012; Wall *et al.*, 2014).  
45 The deep-sea sablefish (*Anoplopoma fimbria*, order Scorpaeniformes, family Anoplopomatidae),  
46 also known as black cod, is an economically important groundfish native to the North Pacific  
47 Ocean ranging from Baja California to the Bering Sea, and throughout the Aleutian Islands into

48 waters off the Kamchatka Peninsula, Russia and northern Japan (Wilkins and Saunders, 1997;  
49 Jacobson *et al.*, 2001). Adult sablefish inhabit the upper continental slope and deep continental  
50 shelf, at depths of 200-1,280 m (Wilkins and Saunders, 1997; Jacobson *et al.*, 2001). Sablefish  
51 support valuable commercial and recreational fisheries in Alaska (Warpinski *et al.*, 2016), Japan,  
52 Russia, and along the U.S. West Coast (Koslow *et al.*, 2000). In addition, thanks to its high  
53 growth rate and market value, sablefish aquaculture is developing in several countries, including  
54 the U.S. and Canada (Sumaila *et al.*, 2007; Sanchez-Serrano *et al.*, 2014; National Marine  
55 Fisheries Service, 2017). The sablefish was first suggested to produce sounds in an unpublished  
56 study of captive fish by Meldrim (1965, pers. comm.) and later based on deep-sea recordings  
57 associated with sablefish presence at deep-sea observatories (Sirovic *et al.*, 2012), but these  
58 observations have not been substantiated. Confirmation of sablefish sound production, together  
59 with a validated description of sablefish sound characteristics, would provide researchers with a  
60 new tool to monitor the species using passive acoustics

61 The goal of this study was to determine if sablefish produce sounds, and if so, to provide  
62 validated sound descriptions to enable future PAM studies of the species. Captive sablefish were  
63 observed and recorded both in an open-water aquaculture facility and in a sablefish research  
64 station.

65

## 66 **II. MATERIALS AND METHODS**

### 67 **A. Data collection**

68 Acoustic recordings were obtained at two facilities: Golden Eagle Sablefish Farm (GESF) (BC,  
69 Canada), where a few hundred sablefish were held in 30 m<sup>2</sup> net pens, and the NOAA Northwest  
70 Fisheries Science Center at Manchester Research Station (NWFSC-MRS) (WA, US), where 20-

71 30 sablefish were held in 3.66 m diameter tanks. There were only mature adult sablefish at GESF  
72 (size range: 46 – 85 cm TL). At the NWFSC-MRS adult sablefish (size range: 35 – 75 cm TL)  
73 were monitored from seven tanks, and juveniles (size range: 3 – 5 cm TL) from a single tank.  
74 The adult sablefish at NWFSC-MRS were distributed in four tanks with mixed sexes, one tank  
75 with only males, and two tanks with unknown sexes.  
76 At both facilities, sablefish were monitored for sound production in real time. Recordings were  
77 made at 96 kHz (24 bit), to a Zoom-H1 recorder (Zoom North America, Happaugue, NY) with an  
78 uncalibrated SQ26-01 hydrophone (sensitivity = -193.5 dB re: 1V/ $\mu$ Pa, Cetacean Research  
79 Technology, Seattle, WA). At the NWFSC-MRS, water pumps were turned off in order to reduce  
80 noise.

81 A Song Meter SM4 recorder (Wildlife Acoustics, Maynard, MA) with an HTI hydrophone  
82 (sensitivity = -165 dB re: 1V/ $\mu$ Pa, High Tech Inc., Long Beach, MS) was also deployed in a tank  
83 containing juvenile sablefish at NWFSC-MRS to collect data on a continuous duty cycle at 96  
84 kHz (16 bit) for up to 4 days. No alterations were made to the regular schedules of pumps and  
85 filters for SM4 recordings.

## 86 **B. Data post-processing**

87 Acoustic measurements of selected parameters of all sablefish sounds were made in Raven Pro  
88 1.5 acoustic software (Center for Conservation Bioacoustics, 2014) following Charif et al.  
89 (2010). Recordings were visually inspected in their entirety to identify sablefish sounds.  
90 Spectrograms were displayed 15 s at a time with frequencies between 0 and 11 kHz (2,825 FFT,  
91 Hann window, 85% overlap). Selection boxes were drawn around each sound to measure the  
92 sound duration, the lowest, peak and highest frequency, the 5<sup>th</sup> and 95<sup>th</sup> percentile frequencies (F.  
93 5% and F. 95%, respectively), and bandwidth 90% (BW 90%) (Charif *et al.*, 2010). Raven Pro

94 automatically computed these values based on the selection boundaries. F. 5% is the frequency  
95 that divides the selection into two frequency intervals containing 5% of the energy at the bottom  
96 and 95% of the energy at the top, while F. 95% is the frequency separating 95% of the energy at  
97 the bottom and 5% at the top. BW 90% is the difference between F. 5% and F. 95% frequencies.  
98 The peak frequency is the frequency at which maximum power occurs within the signal. For  
99 each variable, the measurements reported include minimum, maximum, and mean  $\pm$  SE  
100 (standard error).

101 Sablefish sounds are comprised of a number of broadband ticks that are separated from each  
102 other by variable durations. To differentiate between one sound and the next, an arbitrary cut-off  
103 of 1 s was used.

104 A subset of 72 sablefish sounds from the NWFSC-MRS was used to count the number of ticks  
105 per sound and measure tick-specific duration and frequency parameters (724 FFT, Hann window,  
106 85% overlap). The duration between ticks, or period, was calculated as the time between the  
107 beginning of one tick and the beginning of the next tick (Fig. 1). The inter-tick interval was  
108 calculated as the time between the end of one tick and the beginning of the next tick. The tick  
109 repetition rate was calculated by dividing the number of ticks in a given sound by the duration of  
110 that sound. Within-sound variation in tick frequency structure (F. 5%, peak, F. 95%, and BW  
111 90%) was tested for correlation with elapsed time for 57 unique sounds having 8 or more ticks.  
112 Spearman Rank correlation on log transformed frequencies was performed due to non-linear data  
113 trends using SAS/STAT software (SAS Institute Inc., 2012).

114

### 115 **III. RESULTS**

116 Sounds attributed to adult sablefish were produced by highly agitated fish that displayed  
117 aggressive behavior (charging and nipping the hydrophone) during net pen transfer at GESF.  
118 Similar sounds were recorded from captive specimens at the NWFSC-MRS but were not  
119 associated with any specific behavior.

120 Sounds were recorded at GESF between 2:00 pm and 6:00 pm. Sounds were recorded at the  
121 NWFSC-MRS in 5°C water between 7:00 am and 4:30 pm. At NWFSC-MRS, 2 or more rasps  
122 were heard in each of the four tanks that contained mixed genders, and the tank that had only  
123 males. No rasps were positively identified in the recordings from the two tanks with unknown  
124 genders nor in the tank that contained juveniles.

125 The duration of sablefish sounds ranged between 74 and 10,493 ms (average of  $1342 \pm 96$  SE;  
126 Table I) and they consisted of highly variable trains of 3 to 336 ticks (average  $30 \pm 5$ , Table II).  
127 Due to the similarity of these sounds with cetacean rasps (Marrero Pérez *et al.*, 2017), they were  
128 subsequently referred to as “rasps”. Rasps were highly variable in duration, number of ticks and  
129 frequency structure (Figs. 1 and 2). Rasp frequency ranged from 344 Hz to 33,968 Hz, with an  
130 average peak frequency of  $3,409 \text{ Hz} \pm 118$  (Table I). Additional frequency- and time-based  
131 measurements of sablefish rasps are presented in Table I.

132 In addition to inter-rasp frequency variation, the inspection of individual ticks uncovered wide  
133 intra-rasp frequency variation (Table II). Some rasps were made of ticks whose bandwidth  
134 remained relatively constant throughout the entire call (e.g., the tick with the greatest bandwidth  
135 was only about 400 Hz higher than the tick with the smallest bandwidth). Other rasps presented  
136 bandwidth variability among their ticks as great as 27.5 kHz. For some rasps, the bandwidth was  
137 greater for the first few ticks, and then became narrower as the call progressed (e.g., Figs. 1 and  
138 2A). Most rasps exhibited significant positive correlations between one or more tick frequency

139 measures and elapsed time within the rasp (Supplementary Table I). Examples of both significant  
140 positive and negative trends in tick frequency within a rasp are shown in Fig. 3.  
141 The duration of ticks ranged between 1 and 53 ms, with an average of  $11 \text{ ms} \pm 0.1$  (Table II).  
142 The period ranged between 0.2 and 64.3 ms, with an average of  $6 \text{ ms} \pm 0.1$  (Table II). Within the  
143 same rasp, the period varied as little as 0.2 ms (in a rasp with 3 ticks) and as much as 62.7 ms (in  
144 a rasp with 23 ticks).

145

#### 146 **IV. DISCUSSION**

147 The analysis of the recordings collected at both locations revealed a total of 260 broadband high-  
148 frequency sounds (average  $\sim 3 \text{ KHz}$  peak) referred to as rasps. These sounds were composed of a  
149 series of short (average 11 ms), broadband tick sounds that varied in frequency content and time-  
150 interval between successive ticks (period). These characteristics match the description of the  
151 sounds reported by Meldrim (1965, pers. comm.) from his unpublished study on captive  
152 sablefish, and also support the hypothesis that sablefish could have been the source of the  
153 broadband pulses recorded by Sirovic et al. (2012) in Barkley Canyon. The attribution of the rasp  
154 sounds to sablefish was supported by independent observations in two different facilities. Real-  
155 time observations at GESF indicated that an artificial source of the sounds was highly unlikely,  
156 though the possibility of other biological sources could not be ruled out in the open water pens.  
157 However, recordings of the same type of sounds in tanks of adult sablefish at the NWFSC-MRS  
158 facility confirmed sablefish as the only possible source. The fact that rasps were recorded in  
159 multiple tanks with adults but were absent from other tanks, further reduces the likelihood that  
160 they were artifacts.

161 This newly validated description of sablefish sounds suggests that PAM surveys for sablefish can  
162 be used both in fisheries applications and in studies of deep-sea ecology in areas within the  
163 species' geographic range.

164 Sablefish is one of the top 10 key commercial species in the US, with an important fishery in the  
165 North Pacific Region (Alaska) and Pacific Region (California, Oregon, Washington), where the  
166 total annual landings revenue was between 102-185 million US dollars between 2006-2015  
167 (National Marine Fisheries Service, 2017). In British Columbia, there have been concerns about  
168 the sablefish stock declining below sustainable yield, and management strategies have been  
169 designed to promote stock growth while attempting to maintain the economic performance (Cox  
170 *et al.*, 2011). Stock biomass is currently assessed via trawling surveys and fishery catch data  
171 (Wilkins and Saunders, 1997; Koslow *et al.*, 2000; Warpinski *et al.*, 2016). The use of PAM has  
172 the potential to enhance current sablefish management by providing another independent  
173 monitoring tool.

174 The sablefish fishery in the Gulf of Alaska suffers great reductions in catches due to sperm whale  
175 (*Physeter macrocephalus*) and killer whale (*Orcinus orca*) depredation on longline fishing gear  
176 (Peterson and Hanselman, 2017; Wild *et al.*, 2017). An acoustic decoy has been used to  
177 broadcast vessel-hauling noises known to attract whales at a distance away from the vessel  
178 performing true hauls, thus reducing the number of interactions between whales and fishing  
179 vessels (Wild *et al.*, 2017). It would be interesting to investigate the response of whales to  
180 sablefish sounds. If whales are attracted to rasps, perhaps adding recordings of sablefish rasps to  
181 the vessel-hauling sounds could increase the efficacy of the decoy as an attractant.

182 The soundscape of the deep-sea is poorly known, and fish sounds have been described for very  
183 few deep-sea species (see reviews in: Rountree *et al.*, 2012; Wall *et al.*, 2014; Parmentier *et al.*,

184 2018). This limited knowledge could be due to a series of factors including the need for  
185 specialized equipment, inaccessibility, the non-continuous nature of fish sound production (they  
186 might not be vocal at the moment of recording) and the low amplitude of fish sounds that makes  
187 them susceptible to masking and reduces their detection range (Rountree *et al.*, 2012; Wall *et al.*,  
188 2014). The results presented here add sablefish as one of the few demonstrated cases of sound  
189 production in deep-sea fishes. Knowing what sablefish sound like will also facilitate a more  
190 complete understanding of events that are already being monitored with video at underwater  
191 cabled observatories (Doya *et al.*, 2014) where concurrent acoustic recordings are available.  
192 This study demonstrates that sablefish produce sounds, and therefore this knowledge is useful for  
193 PAM studies. How and why the fish make the sound (if there is a specific function) is unknown,  
194 and what follows is a discussion of some options.

195 The mechanism by which sablefish produce sounds is currently unknown. The phylogenetic  
196 relationships of sablefish to other scorpaeniform fishes is uncertain, but the family  
197 Anoplopomatidae is currently thought to be most closely related to the greenlings  
198 (Hexagrammidae) and sculpins (Cottidae) (Imamura and Yabe, 2002; Shinohara and Imamura,  
199 2007; Nelson *et al.*, 2016). Unfortunately, despite the high diversity of sculpins, sounds have  
200 only been described in two genera (see reviews in: Zeyl *et al.*, 2016; Bolgan *et al.*, 2019) and it is  
201 unknown in greenlings.

202 The broadband high-frequency rasps produced by sablefish are highly unusual among fish, and  
203 previously unknown for any scorpaeniform fish (Bolgan *et al.*, 2019). High frequency fish  
204 sounds have been reported for Clupeiformes (Wilson *et al.*, 2004; Rountree *et al.*, 2018),  
205 Cypriniformes and Salmoniformes (Rountree *et al.*, 2018), Perciformes such as grunts (Bertucci  
206 *et al.*, 2014) and cichlids (Lanzing, 1974; Nelissen, 1978; Kottege *et al.*, 2015; Spinks *et al.*,

207 2017), Siluriformes (Ghahramani *et al.*, 2014; Mohajer *et al.*, 2015) and Gadiformes (Vester *et*  
208 *al.*, 2004). An important distinction between the high frequency sounds produced by sablefish  
209 and those produced by other fishes, is that in most other known cases, the sound production  
210 mechanism involves the gas bladder (Tavolga, 1971; Ladich, 2004) which is absent in sablefish  
211 (Nelson *et al.*, 2016). In fish that lack a swim bladder, the most common sound-producing  
212 mechanism is stridulation, which consists in rubbing hard body parts together, such as bones,  
213 teeth or fin spines (Tavolga, 1971; Ladich, 2004). The high variation in sablefish rasp frequency  
214 is consistent with a stridulatory mechanism (Fine and Parmentier, 2015). For the sculpin species  
215 whose sound production has been described, average peak frequency was between 50 and 500  
216 Hz (Zeyl *et al.*, 2016), which is much lower than that of sablefish ticks ( $5398 \pm 62$  Hz; Table II).  
217 The tick duration for cottid fishes was also shorter than that of sablefish; an average of  $30 \pm 4$  ms  
218 to  $68 \pm 12$  ms (Zeyl *et al.*, 2016) compared to  $11 \pm 0.1$  ms (Table II).  
219 High frequency stridulatory sounds can also be found in some catfish (Ghahramani *et al.*, 2014;  
220 Mohajer *et al.*, 2015), grunt (Bertucci *et al.*, 2014) and cichlid (Lanzing, 1974; Nelissen, 1978;  
221 Kottege *et al.*, 2015; Spinks *et al.*, 2017) species. The average peak frequency for catfish has  
222 been reported to be between  $521 \pm 240$  Hz and  $2895 \pm 276$  Hz (Parmentier *et al.*, 2010), while  
223 the average peak frequency for grunts was  $718 \pm 180$  Hz (Bertucci *et al.*, 2014). Sounds  
224 produced by grunts also consisted of series of units that were themselves composed of a variable  
225 number of pulses (Bertucci *et al.*, 2014). In sablefish, frequency parameters vary greatly between  
226 ticks within the same rasp (Fig. 3), but how the frequency of each unit varies within the series is  
227 not described for grunts, making comparisons difficult. One of the biggest differences between  
228 sablefish rasps and the cichlid high-frequency sounds is the number of components; cichlids  
229 have calls composed of an average of two pulses (Spinks *et al.*, 2017), whereas sablefish rasps

230 have an average of 30 and up to 300 ticks per rasp. This difference translates into an overall  
231 longer duration for rasps.

232 Another less well-known sound production mechanism found in some scorpaeniform species  
233 uses a novel “chordophone” mechanism involving vibrations of tendons to achieve higher  
234 frequencies than possible through muscle contraction alone (see review in Bolgan *et al.*, 2019).  
235 Future research is needed to determine if sablefish sounds are produced by a stridulatory,  
236 chordophone or other mechanism.

237 Although the lack of a swim bladder precludes an air movement sound production mechanism  
238 (see review in Rountree *et al.*, 2018) in sablefish, a superficial similarity to Pacific herring  
239 (*Clupea pallasii*) “fast repetitive tick” (FRT) sounds has implications for PAM applications.  
240 Pacific herring sounds are also composed of long trains of up to 65 ticks (Wilson *et al.*, 2004).  
241 The durations of rasps and FRTs are also comparable, ranging between 0.7-10.5 s (average 1.3 s)  
242 for rasps and 0.6-7.6 s (average 2.6 s) for FRTs (Wilson *et al.*, 2004). However, the period for  
243 rasps was highly variable (presenting no clear pattern), whereas the period for herring FRTs  
244 usually increases or decreases at a steady rate (Wahlberg and Westerberg, 2003; Wilson *et al.*,  
245 2004; Kuznetsov, 2009).

246 Most fishes where hearing has been examined hear best around 200 Hz (Mann *et al.*, 2007) and  
247 have audibility thresholds up to 3 kHz (Ladich and Fay, 2013) but sablefish rasps can get up to  
248 30 kHz and whether they can hear their own sounds remains unknown. The ability to produce  
249 sounds is not necessarily associated with a matching sensitivity to hear them (Ladich, 2000), so  
250 an inability to hear the rasps does not preclude the possibility of other functions such as predator  
251 avoidance. However, high frequency hearing exists for some fishes in the subfamily Alosinae,  
252 which have been reported to hear ultrasounds from 40 to 80 kHz (Mann *et al.*, 2001). Those

253 Alosinae species can also hear the lower frequency components of sounds, down to 200 Hz  
254 (Mann *et al.*, 2001), which indicates that the ability to hear ultrasounds does not rule out the  
255 ability to hear low frequencies. All fishes can detect particle motion through the otolith organs,  
256 but their ability to perceive sound pressure could be limited to the presence of gas-filled  
257 structures (Hawkins and Popper, 2018), which are absent in sablefish (Nelson *et al.*, 2016).  
258 Sablefish rasps have a mean peak of  $3409 \pm 118$  Hz (Table I), which falls within the range of  
259 hearing thresholds of hearing specialists (Ladich, 2000), so it is possible they have evolved a  
260 similar hearing specialist ability through an unknown mechanism not involving the gas bladder.  
261 The hearing abilities of sablefish need to be investigated, and if possible, such studies should  
262 design methodologies that produce data that are comparable between species and laboratories  
263 (Popper *et al.*, 2019).

264 The skilfish, *Erilepis zonifer*, is the only other species in the family Anoplopomatidae (Froese  
265 and Pauly, 2019). A few studies have been conducted on the distribution and biology of the  
266 skilfish (Zolotov *et al.*, 2014), but no data are available regarding their possible sound  
267 production. The capacity for sound production is often shared by species of the same family  
268 (Wall *et al.*, 2014; Spinks *et al.*, 2017; Parmentier *et al.*, 2018), which makes the skilfish a good  
269 candidate for further studies to verify the hypothesis.

270 Although sound production in sablefish has been demonstrated, it remains unclear if the sounds  
271 are produced for an acoustic function such as intra-species communication which requires an  
272 unexpected ability to hear high frequency sounds, an inter-species signal that aids in predator  
273 avoidance which does not require hearing sensitivity, or is entirely incidental to some unknown  
274 physiological function. Regardless, the description of sablefish sounds provides scientists with  
275 the opportunity to use PAM methodologies in the study and management of the species. In

276 addition, even if entirely incidental, determination of the physiological mechanism that produces  
277 such unusual sounds would be informative in and of itself, and suggests that PAM could be used  
278 to monitor spatial and temporal patterns in that physiological process. Future work could include  
279 studies on hearing, sound production mechanism and behaviours associated with vocal activity.

280

## 281 **ACKNOWLEDGEMENTS**

282 The authors would like to thank Hannah Britton-Foster and Kelsie Murchy for their assistance in  
283 the field. Thanks are also due to the crew at the Golden Eagle sablefish farm (Terry Brooks,  
284 Quinten, Dave, Trevor, Mike, Anthony) and personnel at the Manchester Research Station (Rick  
285 Goetz, Cortney Jensen). We are grateful to MERIDIAN for their support. Funding was provided  
286 by DFO Contribution Agreements, an NSERC Discovery grant, CFI and BCKDF equipment  
287 grants, and the Liber Ero Foundation.

288

289 See supplementary material at [URL will be inserted by AIP] for details on the Spearman Rank  
290 Correlation of acoustic log transformed frequency measures of ticks against time for rasps with 8  
291 or more ticks.

292

## 293 **References**

294 Archer, S. K., Halliday, W. D., Riera, A., Mouy, X., Pine, M. K., Chu, J. W. F., Dunham, A., and  
295 Juanes, F. (2018). "First description of a glass sponge reef soundscape reveals fish calls  
296 and elevated sound pressure levels," *Mar. Ecol. Prog. Ser.* **595**, 245-252.

297 Bertucci, F., Ruppe, L., Van Wassenbergh, S., Compere, P., and Parmentier, E. (2014). "New  
298 insights into the role of the pharyngeal jaw apparatus in the sound-producing mechanism of  
299 *Haemulon flavolineatum* (Haemulidae)," J. Exp. Biol. **217**, 3862-3869.

300 Bolgan, M., Soulard, J., Iorio, L. D., Gervaise, C., Lejeune, P., Gobert, S., and Parmentier, E.  
301 (2019). "Sea chordophones make the mysterious /Kwa/ sound: Identification of the emitter  
302 of the dominant fish sound in Mediterranean seagrass meadows," J. Exp. Biol. **222**, 1-11.

303 Center for Conservation Bioacoustics (2014). "Raven Pro: Interactive Sound Analysis Software,"  
304 Version 1.5 [Computer software]. Ithaca, NY: The Cornell Lab of Ornithology. Available  
305 from <http://ravensoundsoftware.com/>.

306 Charif, R., Strickman, L., and Waack, A. (2010). "Raven Pro 1.4 User's Manual." (Ithaca, NY),  
307 379 p.

308 Cox, S. P., Kronlund, A. R., and Lacko, L. (2011). "Management procedures for the multi-gear  
309 sablefish (*Anoplopoma fimbria*) fishery in British Columbia, Canada." *DFO Can. Sci.*  
310 *Advis. Sec.*, Res. Doc. 2011/063 (Fisheries and Oceans Canada, Nanaimo, BC), viii + 45 p.

311 Department of Fisheries and Oceans Canada (2011). "Sgaan Kinghlas Bowie Seamount Marine  
312 Protected Area Monitoring Indicators, Protocols and Strategies." *DFO Can. Sci. Advis.*  
313 *Sec.*, Advis. Rep. 2011/036 (Fisheries and Oceans Canada, Nanaimo, BC), 13 p.

314 Doya, C., Aguzzi, J., Pardo, M., Matabos, M., Company, J. B., Costa, C., Mihaly, S., and Canals,  
315 M. (2014). "Diel behavioral rhythms in sablefish (*Anoplopoma fimbria*) and other benthic  
316 species, as recorded by the Deep-sea cabled observatories in Barkley Canyon (NEPTUNE-  
317 Canada)," J. Mar. Syst. **130**, 69-78.

318 Dufossé, L. (1874). "Recherches sur les bruits et les sons expressifs que font entendre les  
319 poissons d'Europe et sur les organes producteurs de ces phénomènes acoustiques,"  
320 *Annales des sciences naturelles* **5**, 229.

321 Fine, M. L., and Parmentier, E. (2015). "Mechanisms of Fish Sound Production," in *Sound*  
322 *Communication in Fishes. Animal Signals and Communication, vol 4.*, edited by F. Ladich  
323 (Springer, Vienna), pp. 77-126.

324 Fish, M. P. (1948). "Sonic fishes of the Pacific." *Office of Naval Research*, Technical Report No.  
325 2 (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 144 p.

326 Fish, M. P., Kelsey, A. S. J., and Mowbray, W. H. (1952). "Studies on the production of  
327 underwater sound by North Atlantic coastal fishes," *J. Mar. Res.* **11**, 180-193.

328 Froese, R., and Pauly, D. (2019). "FishBase," World Wide Web Electronic Publication, available  
329 from: [www.fishbase.org](http://www.fishbase.org). Retrieved October 25, 2019.

330 Ghahramani, Z. N., Mohajer, Y., and Fine, M. L. (2014). "Developmental variation in sound  
331 production in water and air in the blue catfish *Ictalurus furcatus*," *J. Exp. Biol.* **217**, 4244-  
332 4251.

333 Hawkins, A. D. (1993). "Underwater sound and fish behaviour," in *Behaviour of teleost fishes*,  
334 edited by T. J. Pitcher (Chapman and Hall, London), pp. 129-169.

335 Hawkins, A. D., and Popper, A. N. (2018). "Directional hearing and sound source localization by  
336 fishes," *J. Acoust. Soc. Am.* **144**, 3329-3350.

337 Imamura, H., and Yabe, M. (2002). "Demise of the Scorpaeniformes (Actinopterygii:  
338 Percomorpha): An Alternative Phylogenetic Hypothesis," *Bull. Fish. Sci. Hokkaido Univ.*  
339 **53**, 107-128.

340 Jacobson, L. D., Brodziak, J., and Rogers, J. (2001). "Depth distributions and time-varying  
341 bottom trawl selectivities for Dover sole (*Microstomus pacificus*), sablefish (*Anoplopoma*  
342 *fimbria*), and thornyheads (*Sebastolobus alascanus* and *S. altivelis*) in a commercial  
343 fishery," Fish. Bull. **99**, 309-327.

344 Kaatz, I. M. (2002). "Multiple sound-producing mechanisms in teleost fishes and hypotheses  
345 regarding their behavioural significance," Bioacoustics **12**, 230-233.

346 Koslow, J. A., Boehlert, G. W., Gordon, J. D. M., Haedrich, R. L., Lorange, P., and Parin, N.  
347 (2000). "Continental slope and deep-sea fisheries: Implications for a fragile ecosystem,"  
348 ICES J. Mar. Sci. **57**, 548-557.

349 Kottege, N., Jurdak, R., Kroon, F., and Jones, D. (2015). "Automated detection of broadband  
350 clicks of freshwater fish using spectro-temporal features," J. Acoust. Soc. Am. **137**, 2502-  
351 2511.

352 Kuznetsov, M. Y. (2009). "Traits of acoustic signalization and generation of sounds by some  
353 schooling physostomous fish," Acoust. Phys+ **55**, 866-875.

354 Ladich, F. (2000). "Acoustic communication and the evolution of hearing in fishes," Philos. T.  
355 R. Soc. B **355**, 1285-1288.

356 Ladich, F. (2004). "Sound Production and Acoustic Communication," in *The senses of fish*,  
357 edited by G. von der Emde, J. Mogdans, and B. G. Kapoor (Springer, Dordrecht), pp. 210-  
358 230.

359 Ladich, F., and Fay, R. R. (2013). "Auditory evoked potential audiometry in fish," Rev. Fish  
360 Biol. Fish. **23**, 317-364.

361 Lanzing, W. J. R. (1974). "Sound production in the cichlid *Tilapia mossambica* Peters," J. Fish  
362 Biol. **6**, 341-347.

363 Lindseth, A., and Lobel, P. (2018). "Underwater Soundscape Monitoring and Fish Bioacoustics:  
364 A Review," *Fishes* **3**, 36.

365 Lobel, P. S., Kaatz, I., and Rice, A. N. (2010). "Acoustical behavior in coral reef fishes," in  
366 *Reproduction and sexuality in marine fishes: patterns and processes*, edited by K. S. Cole  
367 (University of California Press, Berkeley, CA), pp. 307-387.

368 Mann, D. A., Cott, P. A., Hanna, B. W., and Popper, A. N. (2007). "Hearing in eight species of  
369 northern Canadian freshwater fishes," *J. Fish Biol.* **70**, 109-120.

370 Mann, D. A., Higgs, D. M., Tavalga, W. N., Souza, M. J., and Popper, A. N. (2001). "Ultrasound  
371 detection by clupeiform fishes," *J. Acoust. Soc. Am.* **109**, 3048-3054.

372 Marrero Pérez, J., Jensen, F. H., Rojano-Doñate, L., and Aguilar de Soto, N. (2017). "Different  
373 modes of acoustic communication in deep-diving short-finned pilot whales (*Globicephala*  
374 *macrorhynchus*)," *Mar. Mamm. Sci.* **33**, 59-79.

375 Mohajer, Y., Ghahramani, Z., and Fine, M. L. (2015). "Pectoral sound generation in the blue  
376 catfish *Ictalurus furcatus*," *J. Comp. Physiol. A* **201**, 305-315.

377 Moulton, J. M. (1963). "Acoustic Behaviour of fishes," in *Acoustic behaviour of animals*, edited  
378 by R. G. Busnel (Elsevier, New York), pp. 210-223.

379 National Marine Fisheries Service (2017). "Fisheries Economics of the United States, 2015."  
380 *U.S. Department of Commerce*, NOAA Technical Memorandum NMFS-F/SPO-170  
381 (National Marine Fisheries Service, Silver Spring, MD), 247 p.

382 Nelissen, M. H. (1978). "Sound production by some Tanganyikan cichlid fishes and a hypothesis  
383 for the evolution of their communication mechanisms," *Behaviour* **64**, 137-147.

384 Nelson, J. S., Grande, T., and Wilson, M. V. H. (2016). *Fishes of the world* (John Wiley & Sons,  
385 Incorporated, New York), 752 p.

386 Parmentier, E., Bahri, M. A., Plenevaux, A., Fine, M. L., and Estrada, J. M. (2018). "Sound  
387 production and sonic apparatus in deep-living cusk-eels (*Genypterus chilensis* and  
388 *Genypterus maculatus*)," Deep Sea Res. Pt. I **141**, 83-92.

389 Parmentier, E., Fabri, G., Kaatz, I., Decloux, N., Planes, S., and Vandewalle, P. (2010).  
390 "Functional study of the pectoral spine stridulation mechanism in different mochokid  
391 catfishes," J. Exp. Biol. **213**, 1107-1114.

392 Peterson, M. J., and Hanselman, D. (2017). "Sablefish mortality associated with whale  
393 depredation in Alaska," ICES J. Mar. Sci. **74**, 1382-1394.

394 Popper, A. N., Hawkins, A. D., Sand, O., and Sisneros, J. A. (2019). "Examining the hearing  
395 abilities of fishes," J. Acoust. Soc. Am. **146**, 948-955.

396 Riera, A., Rountree, R. A., Mouy, X., Ford, J. K., and Juanes, F. (2016). "Effects of  
397 anthropogenic noise on fishes at the SGaan Kinghlas-Bowie Seamount Marine Protected  
398 Area," Proc. Meet. Acoust. **27**, 010005.

399 Riera, A., Rountree, R. A., Pine, M. K., and Juanes, F. (2018). "Sounds of Arctic cod  
400 (*Boreogadus saida*) in captivity: A preliminary description," J. Acoust. Soc. Am. **143**,  
401 EL217-EL321.

402 Rountree, R. A., Bolgan, M., and Juanes, F. (2019). "How Can We Understand Freshwater  
403 Soundscapes Without Fish Sound Descriptions?," Fisheries **44**, 137-143.

404 Rountree, R. A., Gilmore, R. G., Goudey, C. A., Hawkins, A. D., Luczkovich, J. J., and Mann,  
405 D. A. (2006). "Listening to Fish: Applications of Passive Acoustics to Fisheries Science,"  
406 Fisheries **31**, 433-446.

407 Rountree, R. A., Juanes, F., and Bolgan, M. (2018). "Air movement sound production by  
408 alewife, white sucker, and four salmonid fishes suggests the phenomenon is widespread  
409 among freshwater fishes," *PLoS ONE* **13**, 1-32.

410 Rountree, R. A., Juanes, F., Goudey, C. A., and Ekstrom, K. E. (2012). "Is Biological Sound  
411 Production Important in the Deep Sea?," in *The Effects of Noise on Aquatic Life*, edited by  
412 A. N. Popper, and A. D. Hawkins (Springer, New York), pp. 181-183.

413 Rountree, R. A., Perkins, P. J., Kenney, R. D., and Hinga, K. R. (2002). "Sounds of Western  
414 North Atlantic Fishes: Data Rescue," *Bioacoustics* **12**, 242-244.

415 Sanchez-Serrano, S., Paniagua-Chavez, C. G., Segovia, M., and Weirich, C. R. (2014). "Short  
416 and Long-Term Preservation of Sablefish Sperm from Baja California, Mexico," *N. Am. J.*  
417 *Aquacult.* **76**, 245-254.

418 SAS Institute Inc. (2012). "SAS/STAT 12.1 user's guide," Version 12.1 [Computer software].  
419 Cary, NC: SAS Institute Inc. Available from <https://www.sas.com>.

420 Schneider, H. (1966). "Morphology and physiology of sound-producing mechanisms in teleost  
421 fishes," in *Marine Bio-Acoustics*, edited by W. N. Tavolga (Pergamon Press, New York),  
422 pp. 135-158.

423 Shinohara, G., and Imamura, H. (2007). "Revisiting recent phylogenetic studies of  
424 "Scorpaeniformes"," *Ichthyol. Res.* **54**, 92-99.

425 Sirovic, A., Brandstatter, S., and Hildebrand, J. A. (2012). "Fish recordings from NEPTUNE  
426 Canada," *J. Acoust. Soc. Am.* **132**, 1916-1916.

427 Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., and Popper, A. N.  
428 (2010). "A noisy spring: The impact of globally rising underwater sound levels on fish,"  
429 *Trends Ecol. Evol.* **25**, 419-427.

430 Spinks, R. K., Muschick, M., Salzburger, W., and Gante, H. F. (2017). "Singing above the  
431 chorus: cooperative Princess cichlid fish (*Neolamprologus pulcher*) has high pitch,"  
432 *Hydrobiologia* **791**, 115-125.

433 Sumaila, U. R., Volpe, J., and Liu, Y. (2007). "Potential economic benefits from sablefish  
434 farming in British Columbia," *Mar. Policy* **31**, 81-84.

435 Tavalga, W. N. (1971). "Sound Production and Detection," in *Fish Physiology*, edited by W. S.  
436 Hoar, and D. J. Randall (Academic Press, New York), pp. 135-205.

437 Vester, H. I., Folkow, L. P., and Blix, A. S. (2004). "Click sounds produced by cod (*Gadus*  
438 *morhua*)," *J. Acoust. Soc. Am.* **115**, 914-919.

439 Wahlberg, M., and Westerberg, H. (2003). "Sounds produced by herring (*Clupea harengus*)  
440 bubble release," *Aquat. Living Resour.* **16**, 271-275.

441 Wall, C. C., Rountree, R. A., Pomerleau, C., and Juanes, F. (2014). "An exploration for deep-sea  
442 fish sounds off Vancouver Island from the NEPTUNE Canada ocean observing system,"  
443 *Deep Sea Res. Pt. I* **83**, 57-64.

444 Warpinski, S., Herrmann, M., Greenberg, J. A., and Criddle, K. R. (2016). "Alaska's Sablefish  
445 Fishery after Individual Fishing Quota (IFQ) Program Implementation: an International  
446 Economic Market Model," *N. Am. J. Fish. Manage.* **36**, 864-875.

447 Wild, L., Thode, A., Straley, J., Rhoads, S., Falvey, D., and Liddle, J. (2017). "Field trials of an  
448 acoustic decoy to attract sperm whales away from commercial longline fishing vessels in  
449 western Gulf of Alaska," *Fish. Res.* **196**, 141-150.

450 Wilkins, M. E., and Saunders, M. W. (1997). "Biology and management of sablefish,  
451 *Anoplopoma fimbria*," in *International Symposium on the Biology and management of*

452 *Sablefish, 13-15 April 1993*, edited by US Department of Commerce (NOAA Technical  
453 Report NMFS 130, Seattle, Washington), p. 267.

454 Wilson, B., Batty, R. S., and Dill, L. M. (2004). "Pacific and Atlantic herring produce burst pulse  
455 sounds," *P. Roy. Soc. B-Biol Sci.* **271 Suppl.**, S95-S97.

456 Zeyl, J. N., Malavasi, S., Holt, D. E., Noel, P., Lugli, M., and Johnston, C. E. (2016).  
457 "Convergent Aspects of Acoustic Communication in Darters, Sculpins, and Gobies," in  
458 *Fish Hearing and Bioacoustics: an anthology in honor of Arthur N. Popper and Richard R.*  
459 *Fay*, edited by J. A. Sisneros (Springer, Cham), pp. 93-120.

460 Zolotov, O. G., Spirin, I. Y., and Zudina, S. M. (2014). "New data on the range, biology, and  
461 abundance of skilfish *Erilepis zonifer* (Anoplopomatidae)," *J. Appl. Ichthyol.* **54**, 251-265.

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475 Table I. Acoustic variables for sablefish (*Anoplopoma fimbria*) rasps recorded at two facilities,  
 476 showing stats for each of them and both pooled together. SE = standard error of the mean. Min =  
 477 minimum. Max = maximum. F. = Frequency. BW = Bandwidth. F. 5% is the frequency that  
 478 divides the signal into two frequency intervals containing 5% and 95% of the energy in the  
 479 signal. F. 95% is the frequency that divides the signal into two frequency intervals containing  
 480 95% and 5% of the energy in the signal. BW 90% is the difference between the 5% and 95%  
 481 frequencies.

Acoustic variables	Golden Eagle Sablefish Farm (N = 152)			Manchester Research Station (N = 108)			Pooled (N = 260)		
	Min	Max	Mean ( $\pm$ SE)	Min	Max	Mean ( $\pm$ SE)	Min	Max	Mean ( $\pm$ SE)
Low F. (Hz)	535	11668	2446 $\pm$ 111	344	4817	1826 $\pm$ 99	344	11668	2188 $\pm$ 79
F. 5% (Hz)	551	11766	2552 $\pm$ 113	773	5859	2358 $\pm$ 109	551	11766	2471 $\pm$ 80
Peak F. (Hz)	574	12258	3086 $\pm$ 144	434	9234	3863 $\pm$ 192	434	12258	3409 $\pm$ 118
F. 95% (Hz)	1816	13090	5418 $\pm$ 182	2203	30305	9493 $\pm$ 581	1816	30305	7111 $\pm$ 291
High F. (Hz)	2053	13154	6549 $\pm$ 209	2395	33968	11362 $\pm$ 716	2053	33968	8548 $\pm$ 353
BW 90% (Hz)	375	8988	2866 $\pm$ 150	891	25711	7136 $\pm$ 528	375	25711	4640 $\pm$ 269
Duration (ms)	74	4323	732 $\pm$ 52	98	10493	2201 $\pm$ 192	74	10493	1342 $\pm$ 96

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493 Table II. Acoustic variables for the sablefish (*Anoplopoma fimbria*) ticks recorded at the  
 494 Manchester Research Station (N = 2136 except for the period and Inter-Tick interval where N =  
 495 2064, and the tick repetition rate where N = 72). Ticks are the broadband pulses that make up the  
 496 rasps. These ticks were measured from a sub-sample of 72 rasps. SE = standard error of the  
 497 mean. Min = minimum. Max = maximum. F. = Frequency. BW = Bandwidth. F. 5% is the  
 498 frequency that divides the signal into two frequency intervals containing 5% and 95% of the  
 499 energy in the signal. F. 95% is the frequency that divides the signal into two frequency intervals  
 500 containing 95% and 5% of the energy in the signal. BW 90% is the difference between the 5%  
 501 and 95% frequencies.

Acoustic variables	Min	Max	Mean ( $\pm$ SE)
Low F. (Hz)	401	22140	2570 $\pm$ 39
F. 5% (Hz)	797	22406	3178 $\pm$ 39
Peak F. (Hz)	1066	23801	5398 $\pm$ 62
F. 95% (Hz)	2133	32180	10540 $\pm$ 102
High F. (Hz)	2481	41463	12225 $\pm$ 114
BW 90% (Hz)	363	28852	7362 $\pm$ 96
Duration (ms)	1	53	11 $\pm$ 0.1
Number of ticks/rasp	3	336	30 $\pm$ 5
Period (ms)	0.2	64.3	6 $\pm$ 0.1
Inter-Tick Interval (ms)	0	63	5 $\pm$ 0.1
Tick repetition rate (number of ticks/s)	5	63	18 $\pm$ 1

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509 Figure 1. Waveform (top) and spectrogram (bottom) of a short rasp (with fewer than 8 ticks)  
510 produced by sablefish (*Anoplopoma fimbria*) at the Northwest Fisheries Science Center in  
511 Manchester (1800 FFT Hann window with 85% overlap). The temporal measurements are  
512 illustrated: rasp duration (a), tick duration (b) and period (c). A clip of the sound is available as a  
513 multimedia file (Mm. 1).

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515 Figure 2. Three examples of sablefish rasps illustrating the high variation in rasp structures and  
516 variation in tick frequency structure produced by sablefish (*Anoplopoma fimbria*) at the  
517 Northwest Fisheries Science Center in Manchester. Each example includes waveform (top) and  
518 spectrogram (bottom) (1800 FFT Hann window with 85% overlap). A clip of each sound is  
519 available as multimedia files (Mm. 2-4). A) Rasp with a trend for increasing F.5. (Mm. 2). The  
520 top panel is an expansion of the first tick in the middle panel, delineated with a box. B) Rasp  
521 with relatively constant tick frequency structure (Mm. 3). C) Long rasp with high variation in  
522 tick frequency structure (Mm. 4).

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524 Figure 3. Examples of two rasps exhibiting significant correlations of tick frequency parameters  
525 (5% frequency: square, peak frequency: triangle, 95% frequency: circle) with the elapsed time  
526 from the beginning of the rasp. The Spearman Rank Correlation ( $r$ ) is indicated for 95%  
527 frequency (top), peak frequency (middle) and 5% frequency (bottom) with asterisks representing  
528 its significance level (\* = 0.05, \*\* = 0.01, \*\*\* = 0.001, ns = not significant). Top) Positive  
529 correlation (rasp ID 39 in Supplementary table). Bottom) Negative correlation (rasp ID 48 in  
530 Supplementary table). (Color online).









