

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

LRH: M.E. Reiter et al.

RRH: Anurans in subarctic Manitoba, Canada

**Species Composition, Distribution, and Habitat Associations of Anurans in a
Subarctic Tundra Landscape Near Cape Churchill, Manitoba, Canada**

Matthew E. Reiter¹, Clint W. Boal², and David E. Andersen³

*1 Minnesota Cooperative Fish and Wildlife Research Unit, Department of Fisheries,
Wildlife, and Conservation Biology, University of Minnesota, St. Paul, Minnesota 55108
USA, email: reit0127@umn.edu*

*2 U.S. Geological Survey, Texas Cooperative Fish and Wildlife Research Unit, Texas
Tech University, Lubbock, Texas 79409, USA*

*3 U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit,
University of Minnesota, St. Paul, Minnesota 55108, USA*

Key Words: anurans, Boreal Chorus Frog, boreal forest, *Pseudacris maculata*, *Rana
sylvatica*, subarctic tundra, Wood Frog

ABSTRACT.-Distribution, abundance, and habitat relationships of anurans that inhabit

24 subarctic regions are poorly understood, and anuran monitoring protocols developed for
25 temperate regions may not be applicable across large roadless areas of northern
26 landscapes. In addition, arctic and subarctic regions of North America are predicted to
27 experience changes in climate and, in some areas, recently have experienced habitat
28 alteration due to high rates of herbivory by breeding and migrating waterfowl. To better
29 understand subarctic anuran abundance, distribution, and habitat associations, we
30 conducted anuran calling surveys in the Cape Churchill region of Wapusk National Park,
31 Manitoba in 2004 and 2005. We conducted surveys along ~1-km transects distributed
32 across 3 landscape types (coastal tundra, interior sedge meadow/ tundra, and boreal
33 forest/ tundra interface) and estimated the probability of detection and density of Boreal
34 Chorus Frogs (*Pseudacris maculata*) and Wood Frogs (*Rana sylvatica*). We detected a
35 Wood Frog or Boreal Chorus Frog on 22 (87%) of 26 transects surveyed, and probability
36 of detection varied between years and species and among landscape types. Estimated
37 density of both species increased from the coastal zone inland toward the boreal forest
38 edge. Our results suggest that anurans occur across a wide range of habitats in this
39 subarctic tundra landscape, that there are spatial patterns in anuran abundance, and that
40 considerations for both spatial and temporal variation need to be incorporated into
41 surveys for subarctic anurans.

42

43

44

45

46 Concern about declining amphibian populations has received increased attention

47 in North America (Bury et al., 1995) and elsewhere (Burrowes et al., 2004; Lips et al.,
48 2005). Factors implicated in the decline of North American amphibians inhabiting
49 temperate regions include habitat fragmentation and loss (Johnson, 1992), pollution
50 (Bishop 1992), and global climate change (Herman and Scott, 1992; Ovaska, 1997;
51 Pounds, 2001). Changes in global temperatures and increased intensity of UV-B
52 radiation predicted in climate change models (Kickert et al., 1999) could influence the
53 distribution and abundance of anurans throughout North America (Mandronich, 1993;
54 Ovaska, 1997; Pounds, 2001). Arctic and subarctic regions of North America are
55 predicted to experience dramatic changes in climate (Madronich, 1993). In these
56 northern regions, all anurans are at the edges of their distribution and may be easily
57 affected by environmental variation (Ovaska, 1997). For example, increasing average
58 temperatures may result in expansion of some anuran species into regions formerly too
59 cold to support them (Ovaska, 1997), but increasing UV-B radiation could have a
60 significant negative effect on the growth and survival of some anurans (Crump et al.,
61 1999).

62 Some areas of the Canadian Arctic and subarctic have experienced habitat
63 alteration due to high rates of herbivory by breeding and migrating waterfowl (Ankney,
64 1996), especially snow geese (*Chen caerulescens*; Kerbes et al., 1990; Jano et al., 1998).
65 Alteration of coastal vegetation along Hudson Bay has caused hyper-salination of many
66 coastal wetlands (Jefferies and Rockwell, 2002). Extensive feeding on below ground
67 biomass by snow geese in interior tundra meadows and wetlands may reduce the
68 abundance of small wetlands (Abraham and Jefferies, 1997) and change the chemistry of
69 the remaining aquatic habitats suitable for anuran reproduction (Jefferies, 2000).

70 Distribution, abundance, population dynamics, and habitat relationships of anurans
71 inhabiting subarctic regions remain poorly understood and how factors such as habitat
72 loss or alteration, pollution, and global climate change affect anurans in arctic and
73 subarctic regions is unknown.

74 Declines in amphibian populations have resulted in recent efforts to establish
75 standardized monitoring programs for amphibians in North America (e.g., North
76 American Amphibian Monitoring Program; Bishop and Petit, 1992; Heyer et al., 1994;
77 Weir and Mossman, 2004) although these monitoring efforts have not been extended to
78 subarctic regions. Previous data concerning anurans on the Hudson Bay Lowlands within
79 Wapusk National Park, Manitoba do not exist. However, Wood Frogs (*Rana sylvatica*)
80 and Boreal Chorus Frogs (*Pseudacris maculata*) have been reported to occur in the area
81 around the town of Churchill (Shelford and Twomey, 1941; Wrigley, 1974). During a
82 pilot study in June 2002, we detected both Boreal Chorus Frogs and Wood Frogs on
83 standardized surveys in the Cape Churchill region of Manitoba, Canada. Based on these
84 preliminary surveys (C.W. Boal and D.E. Andersen, unpubl. data), we initiated a project
85 in 2004 to assess anuran density, distribution, and habitat associations in the tundra and
86 boreal forest – tundra interface zones of Wapusk National Park. Specifically, we
87 collected data to (1) describe anuran species composition in the region and (2) compare
88 the probability of detection and density of anurans across years, species, and 3 general
89 landscape types.

90

91

METHODS AND MATERIALS

92

93 *Study Area.*-The Hudson Bay Lowland in Manitoba, Canada is an area of low-lying
94 tundra and northern boreal forest ecosystems along the western shores of Hudson Bay
95 (Fig. 1). The region extends from Southern James Bay in Ontario (52° 54' N, 82° 10' W)
96 northwest to just north of the town of Churchill, Manitoba (59° 27' N, 94° 53' W). South
97 of Cape Churchill and within Wapusk National Park (11,475 km²) lies a narrow strip of
98 coastal tundra habitat with coastal salt marshes, beach ridges, and sedge meadows
99 composing the major habitat types (Didiuk and Rusch, 1979; Brook, 2001). In this
100 region, the northern boreal forest begins ~ 10 km from the Hudson Bay coastline. The
101 climate is influenced strongly by Hudson Bay, which can remain frozen for up to 9
102 months of the year. Average daily temperatures range from -26.7°C in January to 12°C in
103 July. Average monthly precipitation ranges from 15.7 mm in February to 68.3 mm in
104 August (Environment Canada, 2005).

105 *Landscape Classification.*-We used ArcView 3.3 (Environmental Systems Research
106 Institute, Inc. © 1992 – 2002), the vegetation classification layer developed by Brook
107 (2001), and habitat categorizations by Didiuk and Rusch (1979) to delineate that portion
108 of Wapusk National Park north of the Broad River and east of the western edge of La
109 Pérouse Bay into 3 landscape types based on physiography and vegetation: (1) Coastal
110 beach ridge/sedge meadow (BRSM), (2) Interior sedge meadow (ISM), and (3)
111 Transition – boreal forest/tundra interface (TRAN; Fig. 1). The BRSM stratum (~330
112 km²) extended from the high tide line to approximately 3 – 5 km inland. This stratum
113 was characterized by low relief, continuous permafrost, poor drainage, beach ridges,
114 coastal marshes, and coastal tundra vegetation (Wellein and Lumsden, 1964; Didiuk and
115 Rusch, 1979). The ISM stratum (~394 km²) began at the western edge of the BRSM

116 stratum and extended westward toward the northern boreal forest edge. This stratum was
117 characterized by reduced numbers of beach ridges, extensive sedge and grass meadow
118 complexes, and shallow water bodies. The TRAN stratum ($\sim 397 \text{ km}^2$) began where
119 spruce trees became increasingly present and consisted primarily of lichen spruce bog,
120 sphagnum spruce bog, lichen melt pond bog, and sedge meadow vegetation types (Brook,
121 2001). Combined, these strata extended from Cape Churchill ($58^\circ 50' \text{ N}$) south to the
122 mouth of the Broad River ($58^\circ 10' \text{ N}$) and from the Hudson Bay coastline ($93^\circ 05' \text{ W}$)
123 west to La Pérouse Bay ($95^\circ 30' \text{ W}$).

124 *Transect Surveys.*-In 2004 and 2005, we used ArcView 3.3 to randomly establish
125 coordinates for the origin of 1-km transects in each stratum. Randomized coordinates in
126 2005 were located $\geq 3 \text{ km}$ from any of the 2004 transects to avoid establishing survey
127 transects in close proximity to areas surveyed in 2004. We were transported by
128 helicopter to each starting location. At the origin, we generated a random compass
129 bearing along which to run the transect. In locations where a random bearing would send
130 the survey crew through impassable terrain (e.g., lakes, rivers, etc.) we randomly selected
131 an alternative bearing. We waited 5 minutes after the helicopter shut down to begin a
132 survey.

133 Based upon results of preliminary surveys conducted in 2002 (C.W. Boal and
134 D.E. Andersen, unpubl. data), sampling methods consisted of an unbounded transect
135 along which we recorded all aural and visual detections of anurans. The primary
136 observer walked each transect and recorded a track of the survey route using a handheld
137 Global Positioning System (GPS) unit. At each anuran detection, the observer recorded
138 the species detected, Call Index Value [CIV: 1 = individuals counted, space between

139 calls, 2 = individuals counted but calls overlap, 3 = full chorus, calls are constant and
140 overlapping (Weir and Mossman, 2004)] by species, estimated distance and bearing from
141 transect line to calling anurans (estimated with a laser rangefinder and a compass),
142 general landscape and vegetation characteristics, weather conditions, and time of
143 observation. Multiple detections from the same location were recorded as a single
144 detection.

145 *Data Analysis.*-We used program DISTANCE (Thomas et al., 2005) to analyze transect
146 data from 2004 and 2005 and fit detection function models. We ranked models using
147 Akaike's Information Criterion corrected for small sample size (AIC_c; Burnham and
148 Anderson, 2002). Because of the low number of detections for some species in some
149 strata, we pooled data to increase sample size and precision of density estimates derived
150 from DISTANCE. We followed methods described in Buckland et al. (2001) to assess
151 the validity of pooling across years, species, and strata. We assessed frequency of
152 detection as a function of distance from the transect to determine whether anurans on the
153 transect line were being detected with probability equal to 1 (an assumption of distance
154 sampling). Our analyses indicated that anurans close to the transect line were being
155 detected at lower probability than those away from the line. We corrected for this
156 possible observer effect on the probability of detection by left truncating the data. We
157 removed all detections observed at <10 m during analysis in DISTANCE. Anuran
158 detections of CIV 2 or CIV 3 indicated that >1 frog was present and we incorporated
159 cluster size (i.e., how many animals were present) in DISTANCE. We used the CIV
160 score of each detection as a relative measure of how many frogs were present, which
161 represented a minimum number of anurans present (e.g., CIV of 2 indicated ≥ 2 anurans

162 present). This approach resulted in minimum density estimates.

163 We fitted 4 separate general detection functions (uniform, half-normal, negative-
164 exponential, hazard rate) to model the observed decline in anuran detections as a function
165 of distance from the transect in the analysis of each of the following scenarios: (1)
166 Anuran detections were pooled across species and strata to compare between years
167 (hereafter, YEAR); (2) Anuran detections were pooled across years and strata to compare
168 between Wood Frogs and Boreal Chorus Frogs (hereafter, SPECIES); (3) Anuran
169 detections were pooled across species and years to compare among strata (hereafter,
170 STRATA). Due to the low number of detections in some scenarios, we allowed only 1
171 cosine adjustment term in models. We used models best supported by the data on the
172 basis of AIC_c to estimate the probability of detection (\hat{p}) and anuran density (\hat{D}) for
173 each year, species, and stratum. Because we were also interested in variation within
174 species across strata, but the number of detections was too small to estimate a detection
175 function with reasonable precision, we calculated the encounter rate (ER = the number of
176 detections per km surveyed) for each species within each stratum. We pooled data across
177 years for calculating encounter rates and evaluated variation in encounter rates between
178 species within strata and across strata within species by comparing 95% confidence
179 intervals (C.I.; Buckland et al., 2001).

180

181 RESULTS

182

183 *Transect Summary.*- We surveyed 15 transects (5 in each stratum) in 2004 and 11
184 transects (3 in the BRSM stratum and 4 in both the ISM and TRAN strata) in 2005. We

185 conducted surveys from 29 June to 2 July 2004 between 0930 and 1900 CDT and from
186 14 to 19 June 2005 between 0922 and 1526 CDT. We completed surveys over a total of
187 24.6 km and transects ($n = 26$) averaged 946 m (SE = 18) in length. Median transect
188 length was 992 m, indicating a strong influence of 5 transects <900 m in length, which
189 we curtailed due to helicopter noise interference or when the presence of a lake prevented
190 surveying to the end of a transect. Surveys averaged 55 minutes to complete in 2004 and
191 64 minutes in 2005.

192 *Anuran Detections.*-YEAR. In 2004, we detected ≥ 1 frog on 11 (73%) of 15 transects and
193 in all 3 strata. We detected anurans aurally on 77 occasions. In 2005, we detected
194 anurans on all 11 transects and in all 3 strata. We detected anurans aurally on 75
195 occasions and visually on 2 occasions (both were Wood Frogs). After imposing a left
196 truncation of 10 m, we used 64 detections in DISTANCE analysis in 2004 and 66
197 detections in 2005. Based on AIC_c , 2 detection function models received substantial
198 support ($\Delta AIC_c < 2.0$) in 2004, and 4 models received substantial support in 2005. The
199 models best supported by the data were different in 2004 (hazard rate) than 2005 (half
200 normal; Table 1). The estimated probability of detection was higher in 2005 ($\hat{p} = 0.32$)
201 than in 2004 ($\hat{p} = 0.13$), based on a comparison of 95% C.I. Although 95% C.I.
202 overlapped, density estimates were over 2 times higher in 2004 than in 2005 (Table 2).

203 SPECIES. Overall, we detected a Wood Frog or Boreal Chorus Frog on 22 (87%)
204 of 26 transects surveyed. After left truncating the data, we used 65 detections for analysis
205 of both Wood Frogs and Boreal Chorus Frogs in DISTANCE. Based on ΔAIC_c , 1
206 detection function model received substantial support for Wood Frogs, and 3 models
207 were supported for Boreal Chorus Frogs (Table 1). The best-supported detection

208 functions were different for Wood Frogs (hazard rate) and Boreal Chorus Frogs (negative
209 exponential; Table 1); however, the estimated probability of detection was only slightly
210 higher for Boreal Chorus Frogs ($\hat{p} = 0.17$) than for Wood Frogs ($\hat{p} = 0.14$; Table 2).

211 The estimated density of Wood Frogs ($\hat{D} = 56.8$ per km²) was higher than for Boreal
212 Chorus Frogs ($\hat{D} = 38.9$ per km²), although 95% C.I. overlapped (Table 2).

213 *STRATA. BRSM stratum:* During 2004 and 2005 surveys, we detected anurans
214 on 5 (63%) of 8 transects in the BRSM stratum. We detected Wood Frogs on 3 (38%)
215 and Boreal Chorus Frogs on 5 (63%) of the 8 transects. The estimated encounter rate for
216 Wood Frogs (0.38 detections per km) was lower than for Boreal Chorus Frogs (2.41
217 detections per km), yet there was a slight overlap of 95% C.I. (Table 3). CIVs for each
218 species are detailed in Fig. 2A. In both 2004 and 2005, we detected more Boreal Chorus
219 Frogs than Wood Frogs, however overall total detections of both species were few.

220 *ISM stratum:* We detected anurans on 8 (89%) of 9 of transects surveyed in 2004
221 and 2005 in the ISM stratum. We detected both Wood Frogs and Boreal Chorus Frogs ≥ 1
222 time on 6 (67%) of 9 transects. The estimated encounter rates for Wood Frogs and
223 Boreal Chorus Frogs were similar with 2.64 and 1.15 detections per km, respectively
224 (Table 3). CIV 1 and CIV 2 were most common for both Wood Frogs and Boreal Chorus
225 Frogs, with few ($n = 1$) full choruses (CIV = 3) detected (Fig. 2B).

226 *TRAN stratum:* We detected anurans on all 9 transects surveyed in the TRAN in
227 2004 and 2005. We detected Wood Frogs and Boreal Chorus Frogs ≥ 1 time on all
228 transects surveyed. The encounter rates for Wood Frogs and Boreal Chorus Frogs were
229 4.64 and 4.29 detections per km, respectively (Table 3). We recorded a steady chorus
230 (CIV = 3) of Wood Frogs on all or part of 3 of 5 transects in 2004, but in 2005, all Wood

231 Frog detections ($n = 16$) were discernable individuals ($CIV = 1$) (Fig. 2C). We detected
232 Boreal Chorus Frogs 14 times in the TRAN stratum in 2004 and 25 times in the TRAN
233 stratum in 2005. The TRAN stratum in 2004 was the only stratum in which we detected a
234 full chorus of Boreal Chorus Frogs at any time during surveys in 2004 and 2005.

235 Overall, we encountered Wood Frogs more often in the TRAN stratum than in the
236 BRSM stratum, but there were no differences between the encounter rates in ISM and
237 TRAN or BRSM and ISM strata based on the comparison of 95% C.I. (Table 3). We also
238 encountered Boreal Chorus Frogs most frequently in the TRAN stratum, but there were
239 no significant differences in encounter rates among strata (Table 3). After left truncating
240 the data at 10 m and pooling across species and years, we used 22, 33, and 75 detections
241 in DISTANCE to estimate the detection function model for the BRSM, ISM, and TRAN
242 strata, respectively. Four models received substantial support in the BRSM stratum, 3
243 models in the ISM stratum, and 2 models in the TRAN stratum (Table 1). Both the
244 BRSM and TRAN strata had the same detection function (negative exponential), but ISM
245 data were best fit using a half-normal function (Table 1). However, the negative
246 exponential model was a competing model ($\Delta AIC_c < 2.0$) for the ISM stratum, and the
247 half-normal was the second highest ranked model in the BRSM stratum. The probability
248 of detection was highest in the BRSM ($\hat{p} = 0.32$) stratum and declined heading inland to
249 the ISM ($\hat{p} = 0.30$) and then TRAN ($\hat{p} = 0.09$) strata. The 95% C.I. for the estimated
250 probability of detection overlapped between ISM and BRSM; however, the probability of
251 detection in the TRAN zone was substantially lower, and its 95% C.I. did not overlap
252 with either BRSM or ISM (Table 2). Estimates of anuran density were highest in TRAN
253 ($\hat{D} = 354.66$), then progressively, and substantially, decreased the further the survey was

254 from the TRAN, with $\hat{D} = 34.34$ in ISM and $\hat{D} = 18.46$ in BRSM (Table 2). Similar to
255 the species-specific encounter rates, pooled species density estimates across strata also
256 decreased from the TRAN to the ISM to the BRSM stratum.

257

258

DISCUSSION

259

260 Despite extensive annual surveys for frogs and amphibians throughout much of
261 North America (Weir and Mossman, 2004), little is known of anuran composition,
262 landscape distribution, and general habitat associations in subarctic regions. We found
263 Wood Frogs and Boreal Chorus Frogs in all 3 landscape types that we sampled in the
264 subarctic region of Cape Churchill, Manitoba. Our estimates suggest that the probability
265 of detecting an anuran was variable across years. Although we were nearly 2 times more
266 likely to detect an anuran in 2005 than in 2004, there were not significant differences in
267 estimated densities across the study area between the 2 years. Probability of detection
268 can be influenced by weather conditions such as wind, barometric pressure, and
269 temperature (Oseen and Wassersug, 2002). We are aware of no data regarding the
270 influence of weather variables on the detection of anurans in tundra habitats; however,
271 recently initiated studies near Cape Churchill are designed to evaluate the effect of these
272 factors on detection rates (D. E. Andersen, unpubl. data).

273 The time during which surveys are conducted, both within years and days (Oseen
274 and Wassersug, 2002), can influence detection probability of anurans. In both years, our
275 surveys occurred approximately 2 weeks prior to the median hatch date of Canada geese
276 (*Branta canadensis*) in the region, which is tied very closely to annual spring phenology

277 (Walter, 1999). Factors that influence Canada goose nest initiation, such as snow melt,
278 also likely affect the timing of reproduction of anurans. In addition, although we
279 conducted our surveys throughout the day in both years, we conducted some surveys later
280 in the day in 2004 than in 2005. Whether this contributed to the observed difference in
281 the probability of detection between years is unknown.

282 Wood Frogs and Boreal Chorus Frogs were the only species we detected during
283 our surveys and the probability of detection and estimates of density were nearly the
284 same for both species. Peak calling in the majority of anuran species is associated with
285 the initiation of the breeding season (Wells, 1977), so detection of anuran species is likely
286 influenced by reproductive ecology. Wood Frogs in temperate regions are spring
287 breeders (Oseen and Wassersug, 2002) and Boreal Chorus Frogs also typically call early
288 in the season (Corn and Muths, 2002). The similarity in the breeding season of these
289 species may have contributed to the similar estimates of probability of detection.
290 However, the magnitude of temporal variation in calling behavior of these species in
291 subarctic regions is unknown. As such, inferences drawn from our estimates of density
292 should be made in context of the limitations of our data.

293 Our data indicated anurans were not detected or distributed equally across the
294 study area. The probability of detecting anurans was equivalent in the BRSM and ISM
295 strata, but much lower in the TRAN stratum. Wind speed likely influences detection
296 probability (personal observation) and has been shown to influence calling in some
297 anuran species (Oseen and Wassersug, 2002). In 2005, average measured wind speeds
298 (km per hour) were substantially higher on transects in the ISM (12.23) and TRAN
299 (11.08) strata than in the BRSM strata (5.78) and may have contributed to some of the

300 observed variation in the probability of detection along this same gradient.

301 The high intensity of calling anurans in the TRAN stratum, especially near the
302 transect (<50 m), may also have limited the probability of detection of anurans farther
303 away, resulting in a low overall probability of detection. Based on DISTANCE analyses,
304 the TRAN stratum had a significantly smaller effective strip width (22.28 m) than either
305 the ISM (75.62 m) or BRSM (80.11 m) strata. In contrast, density of anurans increased
306 substantially from the BRSM stratum to the TRAN stratum. We also encountered Wood
307 Frogs with higher frequency along the same gradient from BRSM to TRAN strata.
308 However, we encountered Boreal Chorus Frogs more frequently in the BRSM stratum
309 than in the ISM stratum, and most frequently in the TRAN stratum. The magnitude of
310 variation in encounter rates across strata appeared less than the density estimates based
311 on DISTANCE, and is most likely due to incorporating the cluster size of detections (i.e.,
312 how many animals are present) in DISTANCE. We used the CIV score of each detection
313 as a relative measure of the minimum number of anurans present for subsequent
314 minimum density estimates using DISTANCE. These minimum density estimates are
315 likely more appropriate than the relative measure of anuran abundance derived from
316 encounter rates, which do not account for the number of anurans present at each detection
317 location. Estimated density and encounter rates were highest in the TRAN stratum.
318 Weather conditions in the BRSM and ISM strata are strongly influenced by Hudson Bay,
319 which can remain frozen for up to 9 months of the year. Even though both Wood Frogs
320 and Boreal Chorus Frogs are able to survive through harsh winter conditions, they may
321 experience greater survival and reproductive success in the comparatively milder
322 conditions that exist near the boreal forest edge.

323 Although we pooled data across years, species, and strata, our sample sizes (i.e.,
324 the number of detections) were still small for analyses based on distance sampling. This
325 was primarily due to logistical and fiscal constraints of surveying an area accessible only
326 by foot or helicopter during spring and summer. Furthermore, the utility of program
327 DISTANCE is limited when species are rare and detections are few (Buckland et al.,
328 2001). In the ISM and BRSM strata, both Wood Frogs and Boreal Chorus Frogs were
329 detected infrequently, and thus estimates of detection probability and density are
330 imprecise. We also were unable to use DISTANCE to estimate the probability of
331 detection or density for each species within each of the 3 landscape strata due to the very
332 low number of detections the BRSM and ISM strata. Future surveys should consider
333 increasing sampling effort in some zones to achieve adequate detection sizes. Our data
334 also suggested that anuran behavior may be influenced by observers. Anuran detection
335 frequency within 10 m of transects was substantially lower than detection frequency
336 farther from transects. In our analyses, we accounted for observer effects by left
337 truncating data, but truncation reduced sample size. Alternative methods that would
338 reduce possible observer effects on detections should be considered for future surveys in
339 this region.

340 Ours is one of the first studies to examine patterns of distribution and density of
341 anurans in a subarctic tundra ecosystem. Because arctic and subarctic regions are
342 projected to experience dramatic changes in climate, and because biotic factors (e.g.,
343 intensive and extensive foraging by waterfowl) have already affected arctic and subarctic
344 landscapes, it is imperative to better understand current anuran distribution and
345 abundance, and to develop methods and programs to monitor anurans in arctic regions.

346 Our data provide a critical first assessment of the distribution and ecology of subarctic-
347 dwelling anurans.

348 *Acknowledgements.*-We thank Parks Canada, Wapusk National Park for providing
349 funding for helicopter support to conduct anuran calling surveys in 2004 and 2005.
350 Manitoba Conservation, the Mississippi Flyway Council, and Parks Canada provided
351 logistical support in the form of maintenance and operation of the Nestor One research
352 camp at Cape Churchill, from which surveys were conducted. Hudson Bay Helicopters,
353 Ltd. provided flight support. We especially wish to acknowledge Murray Gillespie
354 (Manitoba Conservation), Bob Reside (Parks Canada), and Joan Brauner, Scott Dewindt,
355 and Ryan Doty of Hudson Bay Helicopters for their efforts in support of field work in
356 2004 and 2005.

357

358 LITERATURE CITED

359

360 Abraham, K.F., and R.L. Jefferies, 1997. High goose populations: causes, impacts, and
361 implications. In B.D.J. Batt (ed.), Arctic Ecosystems in Peril: Report of the Arctic Goose
362 Habitat Working Group, pp. 2-72. Arctic Goose Joint Venture special publication, U.S.
363 Fish and Wildlife Service, Washington, D.C., and Canadian Wildlife Service, Ottawa,
364 Ontario, Canada.

365

366 Ankney, C.D. 1996. An embarrassment of riches: too many geese. *Journal of Wildlife*
367 *Management* 60:217-223.

368

369 Bishop, C.A. 1992. The effects of pesticides on amphibians and the implications for
370 determining causes of declines in amphibian populations. In C.A. Bishop and K.E. Petit
371 (eds.), *Declines in Canadian Amphibian Populations: Designing a National Monitoring*
372 *Strategy*. Occasional Paper No. 76, pp. 67-70. Canadian Wildlife Service, Ottawa,
373 Ontario, Canada.

374

375 Bishop, C.A., and K.E. Petit (eds.). 1992. *Declines in Canadian Amphibian Populations:*
376 *Designing a National Monitoring Strategy*. Occasional Paper No. 76. Canadian Wildlife
377 Service. Ottawa, Ontario, Canada.

378

379 Brook, R.K. 2001. *Structure and Dynamics of the Vegetation of Wapusk National Park*
380 *and the Cape Churchill Wildlife Management Area of Manitoba: Community and*
381 *Landscape Scales*. Unpubl. M.S. Thesis, Natural Resources Institute, University of
382 Manitoba, Winnipeg, Manitoba, Canada.

383

384 Buckland, S.T., D.R., Anderson, K.P., Burnham, J.P., Laake, D.L., Borchers, and L.,
385 Thomas. 2001. *Introduction to Distance Sampling*. Oxford University Press, London,
386 UK.

387

388 Burnham, K.P., and D.R Anderson. 2002. *Model Selection and Inference: A Practical*
389 *Information-Theoretic Approach, Second Edition*. Springer-Verlag, New York, New
390 York.

391

392 Burrowes, P.A., R.L. Joglar, and D.E. Green. 2004. Potential causes for amphibian
393 declines in Puerto Rico. *Herpetologica* 60:141-154.
394

395 Bury, R.B., P.S. Corn, C.K. Dodd, R.W. Diarmid, and N.J. Scott. 1995. Amphibians. In
396 E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (eds.), *Our Living*
397 *Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S.*
398 *Plants, Animals, and Ecosystems*, pp. 124 – 127. U.S. Department of the Interior,
399 National Biological Service, Washington, D.C.
400

401 Corn, P.S., and E. Muths. 2002. Variable breeding phenology affects the exposure of
402 amphibian embryos to ultraviolet radiation. *Ecology* 83:2958-2963.
403

404 Crump, D., M. Berrill, D. Coulson, D. Lean, L. McGillivray, and A. Smith. 1999.
405 Sensitivity of amphibian embryos, tadpoles, and larvae to enhanced UV-B radiation in
406 natural pond conditions. *Canadian Journal of Zoology* 77:1956-1966.
407

408 Didiuk, A.B., and D.H. Rusch. 1979. Ecology of broods of Canada geese in northern
409 Manitoba. Final research report, Wisconsin Cooperative Wildlife Research Unit,
410 Madison.
411

412 Environment Canada. 2005. [http://: www.climate.weatheroffice.ec.gc.ca](http://www.climate.weatheroffice.ec.gc.ca).
413

414 Herman, T.B., and F.W. Scott. 1992. Assessing the vulnerability of amphibians to

415 climatic warming. In C.A. Bishop and Petit, K.E. (eds.), Declines in Canadian Amphibian
416 Populations: Designing a National Monitoring Strategy, Occasional Paper No. 76, pp. 46
417 – 49. Canadian Wildlife Service, Ottawa, Ontario, Canada.

418

419 Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster (eds.).
420 1994. Measuring and Monitoring Biological Diversity: Standard Methods for
421 Amphibians. Smithsonian Institution Press, Washington, D.C.

422

423 Jano, A.P., R.L. Jefferies, and R.F. Rockwell. 1998. The detection of vegetational change
424 by multitemporal analysis of LANDSAT data: the effects of goose foraging. *Journal of*
425 *Ecology* 86:93-99.

426

427 Jefferies, R.L. 2000. Allocthonous inputs: integrating population changes and food web
428 dynamics. *Trends in Ecology and Evolution* 15:19-22.

429

430 Jefferies, R.L., and R.F. Rockwell. 2002. Foraging geese, vegetation loss and soil
431 degradation in an arctic salt marsh. *Applied Vegetation Science* 5:7-16.

432

433 Johnson, B. 1992. Habitat loss and declining amphibian populations. In C.A. Bishop and
434 K.E. Petit (eds.). Declines in Canadian Amphibian Populations: Designing a National
435 Monitoring Strategy. Occasional Paper No. 76, pp. 71 – 77. Canadian Wildlife Service.
436 Ottawa, Ontario, Canada.

437

438 Kerbes, R.H., P.M Kotanen, and R.L. Jefferies. 1990. Destruction of wetland habitats by
439 lesser snow geese: a keystone species on the west coast of Hudson Bay. *Journal of*
440 *Applied Ecology* 27:242-258.
441

442 Kickert, R.N., G. Tonella, A. Simonov, and S.V. Krupa.1999. Predictive modeling of
443 effects under global change. *Environmental Pollution* 100:87-132.
444

445 Lips, K.R., P.A. Burrowes, J.R. Mendelson III, and G. ParraOlea. 2005. Amphibian
446 declines in Latin America: widespread declines, extinctions, and impacts. *Biotropica*
447 37:163-165.
448

449 Madronich, S. 1993. UV radiation in the natural and perturbed atmosphere. In M. Tenini
450 (ed.), *UV-B Radiation and Ozone Depletion: Effects on Humans, Animals, Plants,*
451 *Microorganisms, and Materials*, pp.17-61. Lewis Publishers, Boca Raton, Florida.
452

453 Oseen, K.L., and R.J. Wassersug. 2002. Environmental factors influencing calling in
454 sympatric anurans. *Oecologia* 133:616-625.
455

456 Ovaska, K. 1997. The vulnerability of amphibians in Canada to global warming and
457 increased solar ultraviolet radiation. In D.M. Green (ed.), *Amphibians in Decline:*
458 *Canadian Studies of a Global Problem*, pp. 206-225. Society for the Study of Amphibians
459 and Reptiles, St. Louis, Missouri.
460

461 Pounds, J.A. 2001. Climate and amphibian declines. *Nature* 410:639-640.
462
463 Thomas, L., J.L. Laake, S. Strindberg, F.F.C. Marques, S.T. Buckland, D.L. Borchers,
464 D.R. Anderson, K.P. Burnham, S.L. Hedley, J.H. Pollard, J.R.B. Bishop, and T.A.
465 Marques. 2005. Distance 5.0, Beta 5. Research Unit for Wildlife Population
466 Assessment, University of St. Andrews, St. Andrews, UK. [http://www.ruwpa.st-
468 and.ac.uk/distance/](http://www.ruwpa.st-
467 and.ac.uk/distance/).
469 Shelford, V.E., and A.C. Twomey. 1941. Tundra animal communities in the vicinity of
470 Churchill, Manitoba. *Ecology* 22:47-69.
471
472 Walter, S.E. 1999. Nesting Ecology of Eastern Prairie Population Canada Geese. Unpubl.
473 Ph.D. Dissertation, University of Wisconsin, Madison.
474
475 Weir, L.A., and M.J. Mossman. 2004. The protocol and history of the amphibian calling
476 survey of the North American Amphibian Monitoring Program (NAAMP). In M.J.
477 Lannoo (ed.), *Status and Conservation of US Amphibians*, Volume 1, pp.565 – 584.
478 University of California Press, Berkeley.
479
480 Wellein, E.G., and H.G. Lumsden. 1964. Northern forests and tundra. In J.P. Lunduska
481 (ed.), *Waterfowl Tomorrow*, pp. 67-76. United States Government Printing Office,
482 Washington, D.C.
483

484 Wells, K.D. 1977. The social behaviour of anuran amphibians. *Animal Behavior* 25:666-
485 693.

486

487 Wrigley, R.E. 1974. Ecological notes on animals of the Churchill region of Hudson Bay.
488 *Arctic* 27:201-213.

489

490

491

492

493

494

495

496

497

498

499

500

501

502

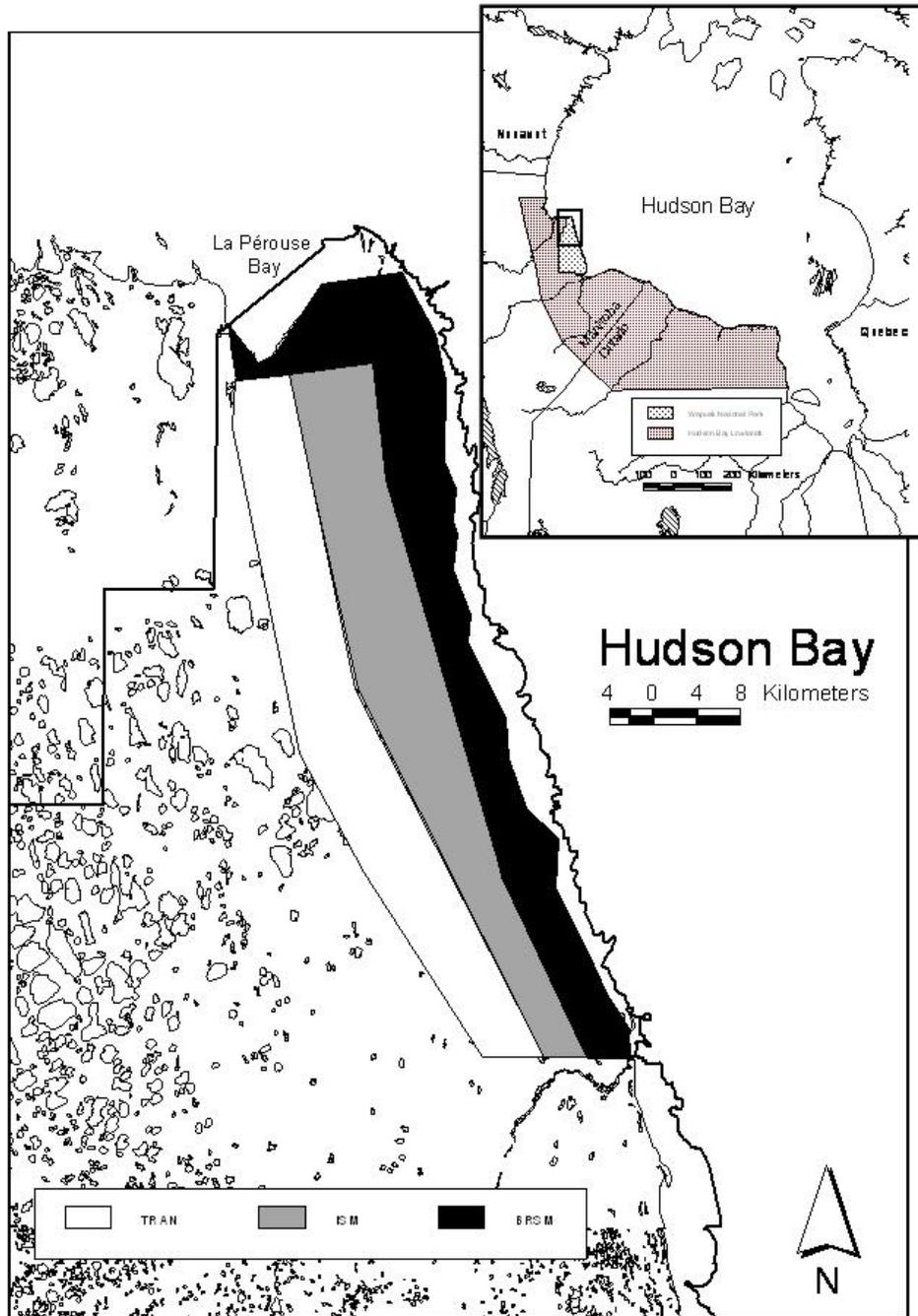
503

504

505

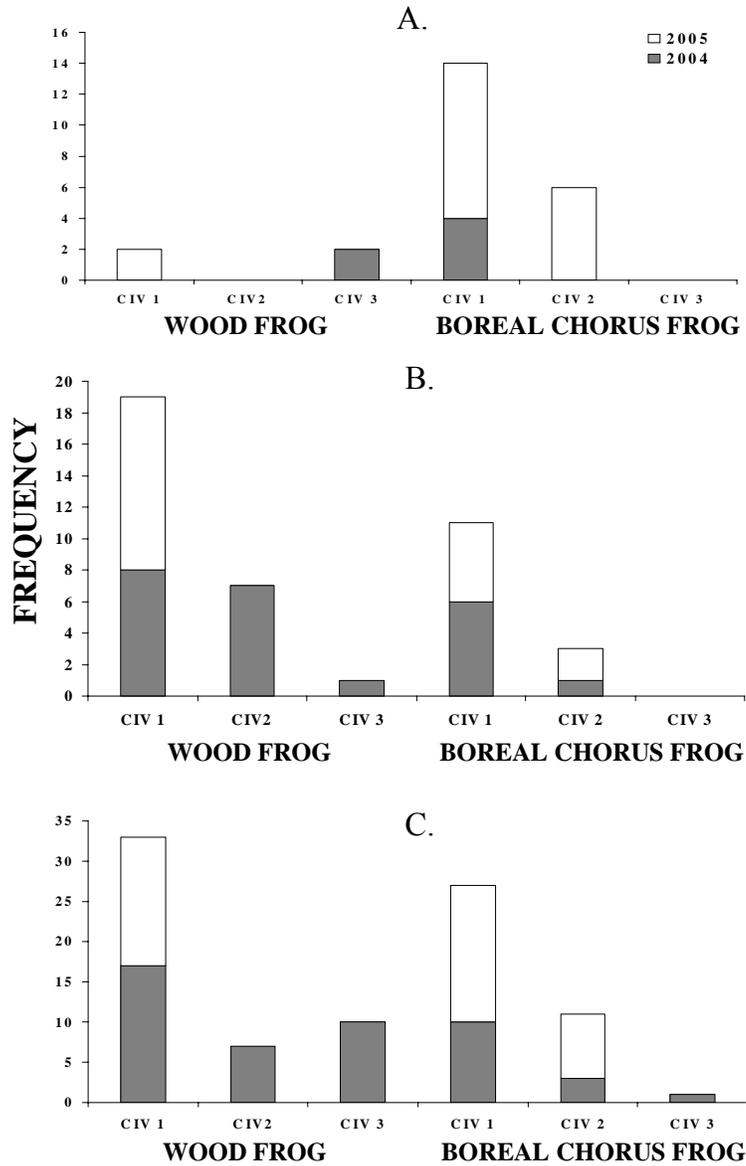
506

507 FIG. 1. Three vegetation/physiographic strata at Cape Churchill: beach ridge/ sedge
508 meadow (BRSM), interior sedge meadow (ISM) and boreal forest/ tundra interface
509 (TRAN) within Wapusk National Park, Manitoba, Canada.



510

511 FIG. 2. Frequency of each level (1, 2, and 3) of call index values (CIV) observed for each
 512 anuran species (Wood Frog or Boreal Chorus Frog) in each year (2004 or 2005) in the
 513 (A) beach ridge/ sedge meadow (BRSM), (B) interior sedge meadow (ISM) and (C)
 514 boreal forest/ tundra interface (TRAN) in Wapusk National Park, Manitoba, Canada.



515