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Mysis salemaai in Ireland: new occurrences and existing population declines

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1 SHORT COMMUNICATION

2

3 ***MYSIS SALEMAAI* IN IRELAND: NEW OCCURRENCES AND EXISTING POPULATION**

4 **DECLINES**

5

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16 ABSTRACT

17

18 We report three new occurrences of *Mysis salemaai*, a conservationally important glacial relict at the
19 southern limit of its range, in Castlewellan Lake, Lough Scolban and Lough Macnean Upper, in the
20 North of Ireland. This increases the number of lakes in Ireland where the species has been recorded
21 to fourteen. We consider lake area and maximum lake depth as factors that might determine the long-
22 term survival of *M. salemaai* populations and show that these populations tend to occur in relatively
23 large, deep, lakes. We also show that population densities in Lough Neagh and Lough Erne are
24 declining.

25

26 INTRODUCTION

27

28 The opossum shrimp *Mysis salemaai* Audzijonytė & Väinölä, 2005 (previously known as *M. relicta*
29 Lovén, 1862) is a euryhaline glacial relict, a stenothermic species found in northern Europe, including
30 Ireland, and northern Siberia (Audzijonyte & Väinölä, 2005). The species occurs at its southern
31 distributional limit in Ireland and is the only native member of its taxonomic order in Irish freshwaters,
32 making it conservationally important. It is also an important consumer and prey item for fish in some
33 lake ecosystems (Griffiths, 2007).

34 Many studies have noted the sensitivity of the *Mysis relicta* species group, of which *M.*
35 *salemaai* is a member, to high temperatures (see references in Griffiths, 2007), but the effects of
36 oxygen concentration and/or eutrophication are less clear, with some populations tolerating low
37 oxygen concentrations (Horppila *et al.*, 2003; Sandeman & Lasenby, 1980). Penk *et al.* (2014) show
38 that high temperatures and low oxygen concentrations reduce *M. salemaai* survival. Consequently, *M.*
39 *salemaai* is most likely to have persisted since the last glaciation in cold-water habitats and is
40 therefore most likely to occur in large, deep, cold-water, low productivity, lakes.

41 Penk (2011) reviewed and updated information on the distribution of *M. salemaai* in Ireland,
42 and provided some information on densities and ecology of the species: Penk *et al.* (2014, Table S3)
43 provide a record, but no density information, for an additional lake, Lough Gowna. The purpose of this
44 short communication is to build on the work by Penk (2011; 2014) by:

45 (a) documenting three new occurrences of *M. salemaai* in Ireland

- 46 (b) investigating the effect of maximum lake depth on *M. salemaai* density
47 (c) investigating the influence of lake area and maximum depth on *M. salemaai* occurrence
48 (d) investigating the temporal trends of two large existing populations of *M. salemaai* found in Lough
49 Neagh (Andrew & Woodward, 1993; Griffiths, 2007) and in Lough Erne.

50

51 MATERIALS AND METHODS

52

53 All *M. salemaai* were caught during daylight by vertical zooplankton net hauls, over varying vertical
54 haul distances. Net types differed between studies in diameter (0.3-0.5m) and mesh size (180-
55 1000 μ m), but Griffiths (2007) found no effect on estimated densities when comparing the two very
56 different sized nets used in Lough Neagh. All catches, of adults and juveniles combined, are
57 expressed as densities (numbers per m³).

58 Penk (2011) provided *M. salemaai* vertical net haul density estimates for most of the lakes in
59 this study. However, *M. salemaai* was found in Oughter Lough only in epibenthic sled samples owing
60 to the shallow nature of this lake. In our analysis the mean density of *M. salemaai* for Oughter Lough
61 was arbitrarily set to the same density value (0.05 individuals.m⁻³) as in the lake with the lowest
62 density sampled by vertical hauls (Lough Scolban).

63 We sampled 51 lakes between 2012 and 2013 in the northern part of the island of Ireland.
64 These lakes were sampled seasonally (once in spring, summer and autumn) for chemical and
65 biological properties.

66 Area and depth data for 136 lakes in Ireland, compiled by Duck and Cawardine (2005), were
67 used to supplement the information in Penk (2011).

68

69 LOUGHS NEAGH AND ERNE: TEMPORAL TRENDS IN *M. SALEMAAI* DENSITY

70 In Lough Neagh *M. salemaai* densities were determined from samples enumerated approximately
71 monthly between 2005-2012 and weekly samples collected between 1993-2005 (Griffiths, 2007).

72 Lough Neagh *M. salemaai* were sampled at two 10m sites, 3km apart, in the north of the lough from
73 1993-2005 and 2005-2012 respectively. The timing and frequency of sampling in Lough Erne was
74 more variable (4-20 samples per year).

75 Penk (2011) collected *M. salemaai* samples in March 2009. Mysid catches vary seasonally
76 and, when comparing our data with the Penk dataset, we calculated mean densities for Loughs
77 Neagh and Erne from catches averaged over the February-April, 2005-12 period, due to the low
78 numbers caught.

79 The long-term trends in Lough Neagh and Erne catch data presented here are calculated as
80 the mean density in all samples collected in each calendar year.

81

82 STATISTICAL ANALYSIS

83 Relationships between *M. salemaai* densities and sampling or lake depth and area were examined by
84 linear regression or product-moment correlation coefficients (r). Differences between lakes with or
85 without *M. salemaai* were investigated by univariate analysis of variance, while the effect of sampling
86 site on *Mysis* density in Lough Neagh was tested by analysis of covariance (F). All analyses used
87 Systat 13 software.

88 Loughs Neagh and Erne densities (log-transformed) were examined for temporal congruence
89 by time series analysis. Following standard procedures (Wilkinson, Blank & Gruber, 1996), long term
90 trends in density in each lake series were removed by differencing and then checked that no auto-
91 correlation remained before testing for cross correlation between the two time series. There was one
92 missing and two zero density values for the Lough Erne dataset and densities for these years were
93 automatically estimated by interpolation using local quadratic smoothing.

94 Lough Erne had a much lower *M. salemaai* density than expected for the vertical haul distance
95 of 55m: it was highlighted as a statistical outlier (Cook's $D = 1.03$) and omitted from the *M. salemaai*
96 regression analyses.

97 For cross lake comparisons, *M. salemaai* density estimates (Table 1) were adjusted to a
98 standard vertical haul distance (25m, the mean across samples).

99

100 RESULTS

101

102 NEW OCCURRENCES: CASTLEWELLAN LAKE, LOUGH SCOLBAN AND LOUGH MACNEAN

103 UPPER

104 *M. salemaai* were recorded in just two of the 51 lakes sampled: Castlewellan Lake and Lough
105 Scolban. *M. salemaai* were also found in the gut contents of perch (*Perca fluviatilis* L. 1758) from
106 Lough Scolban (K. Gallagher, unpublished observations). *M. salemaai* was found in Lough Macnean
107 Upper in 1989 (A. G. Fitzsimons, personal communication). This lake was not sampled in the 2012/13
108 51 lake survey. With the exception of Castlewellan Lake, all previous records come from four large
109 catchments (Shannon, Corrib, Erne and Neagh) (Table 1). Lough Scolban drains to Lough Erne via a
110 short channel. At present, Castlewellan Lake does not appear to have an outflow (R. McFaul,
111 personal communication), but is closest to the Carrigs River which drains to the Irish Sea at Dundrum
112 Inner Bay.

113 Six *M. salemaai* were also found in August 2005 in sweep net samples from Lough Beg (D.
114 Griffiths, unpublished observations), 2km downstream of Lough Neagh: this probably resulted from
115 washout from Lough Neagh and consequently it is not counted as a new population.

116

117 FACTORS INFLUENCING *M. SALEMAAI* DENSITY AND OCCURRENCE

118 *M. salemaai* net catch density increased with vertical haul distance ($r = 0.55$, $n = 20$, $P = 0.01$; Fig. 1a).
119 Densities increased with maximum lake depth ($r = 0.65$, $n = 11$, $P < 0.05$; Fig. 1b). Neither lake area
120 nor trophic state were significant predictors of *M. salemaai* density ($r = 0.36$, $n = 12$, $P > 0.2$; $r = 0.26$, n
121 $= 12$, $P > 0.7$ respectively).

122 Lakes with *M. salemaai* had significantly greater areas and maximum depths than those
123 without (Fig. 2), but mean depths did not differ (univariate ANOVAs of log-transformed values $F_{1,129} =$
124 64.34 , $P < 0.001$, $F_{1,127} = 12.82$, $P < 0.001$, $F_{1,127} = 0.12$, $P > 0.7$ respectively).

125

126 LOUGH NEAGH AND LOUGH ERNE: TEMPORAL TRENDS IN *M. SALEMAAI* DENSITY

127 There was no significant difference in *M. salemaai* temporal trends between the two Lough Neagh
128 sites (ANCOVA; slopes $F_{1,17} = 0.23$; intercepts $F_{1,18} = 0.00$), so we present the analysis for the
129 combined data after dropping one of the data points, selected at random, for the overlap year of 2005.
130 While mean densities have fluctuated over time there were significant declines in both lakes (Lough
131 Neagh $r = -0.74$, $n = 20$, $P < 0.001$; Lough Erne $r = -0.39$, $n = 24$, $P < 0.05$). The density of *M. salemaai*
132 in Lough Neagh declined by 96% in mean abundance between 1993 and 2012, while in Lough Erne
133 there was a much weaker decline of 58% over the same period (Fig. 3). Over this period there was no

134 significant cross correlation between the two time series, contrary to what would be expected from a
135 large-scale environmental effect on population density.

136

137 DISCUSSION

138

139 *Mysis salemaai* is a euryhaline, relatively young, species which is thought to have colonised
140 freshwaters from coastal populations towards the end of the last glaciation (Audzijonyte & Väinölä,
141 2006). In Ireland, *M. salemaai* populations have been found in both large and small lakes (Penk 2011;
142 2014 and this paper). Long-term population persistence is most likely in large, deep, lakes as these
143 waterbodies can potentially support larger populations: our results are consistent with this statement.
144 Population density was greater in deeper lakes. These lakes are likely to stay cooler than shallow
145 lakes in summer because of their greater volume.

146 *M. salemaai* populations in Lough Scolban and other small lakes might also be maintained in
147 the long-term because of connections to large lakes within the catchment, which may permit
148 recolonization in the event of local extinction (the rescue effect, Brown & Kodric-Brown, 1977).
149 Recolonization would be more likely to occur between lakes at similar elevations, connected by short
150 channels with low discharges: Lough Scolban is only 4m higher than Lough Erne and connected by a
151 channel about 2km long, while Lough Macnean Upper, although approximately 20km from Lough
152 Erne, is only 2m higher. Penk & Minchin (2014) showed that *M. salemaai* moved into shallow waters
153 in autumn, a behaviour conducive to colonisation of lakes via rivers.

154 However, Castlewellan Lake is a small lake not currently connected to any of the other
155 catchments with *M. salemaai* populations and all but the Castlewellan Lake population were found in
156 catchments which drain to the west or north of Ireland. There is geological evidence of drainage from
157 Lough Neagh to the southeast during the last glacial period (Knight, 2002) and, while there is no
158 evidence of a connection, it is possible that water flowed into Castlewellan Lake postglacially (S.
159 Roberson, personal communication). Colonisation from the sea seems unlikely given the lake's
160 elevation (twice that of other populations) and proximity to the coast, implying a steep channel
161 gradient if a connection existed in the past. Hull (1881, p12) notes, without further comment, that
162 'Castlewellan Lake is only partly artificial': a smaller lake appears to have been extended by previous
163 estate owners (R. Kernohan, personal communication).

164 In the latter half of the 20th century, intentional introductions of *Mysis relicta* and *M. diluviana*
165 Audzijonytė & Väinölä, 2005 were common in Scandinavia and North America respectively, in an
166 effort to boost salmonid fisheries (Nesler & Bergersen, 1991). Castlewellan Lake is stocked with
167 brown (*Salmo trutta* L.) and rainbow trout (*Oncorhynchus mykiss* Walbaum)(body weight about 400g)
168 annually, between January and October, from Movanagher Fish Farm, about 20km downstream of
169 Lough Neagh. A Ministry of Agriculture for Northern Ireland (1969) report notes large numbers of
170 *Mysis relicta* (now *M. salemaai*) in the fish farm water supply and outlines the intention to introduce
171 them to Castlewellan Lake, as a natural source of fish food 'to a lake where it is known they are not
172 indigenous'. Following introduction in March 1969, surveys conducted in Castlewellan Lake in
173 November 1979 and 1980 revealed the presence of *Mysis* in the stomachs of 50% and 21%
174 respectively of fish (presumably trout) caught. Prior to this, stomach content analysis had not shown
175 *Mysis* to be present in the lake (Department of Agriculture Science Service, 1980). While the
176 information in the reports lacks detail it does suggest that the *M. salemaai* population in Castlewellan
177 Lake is most likely to have been introduced. It's persistence to the present day illustrates the
178 potential for establishing a successful, non-indigenous, population.

179 Are there still more *M. salemaai* populations yet to be discovered in Ireland? The species has
180 not been recorded from Lough Mask, a large deep lake, separated from Lough Corrib, where it does
181 occur, by a short, low gradient, channel: this might be a real absence or simply due to inadequate
182 sampling. The sampling protocol for zooplankton in Ireland tends to favour the use of vertical net
183 hauls in preference to horizontal tows. The majority of Irish lakes are shallow and consequently *M.*
184 *salemaai*, an active swimmer, is more likely to move away during net placement and hence less likely
185 to be sampled by the short vertical hauls taken in shallow lakes. However, small, shallow, lakes are
186 also less likely to persist over geological time than larger, deeper ones (Wetzel, 2001) and so, unless
187 closely connected to large lakes, *M. salemaai* populations are unlikely to be found in shallow lakes.

188 The catch density-depth analysis identified Lough Erne as a statistical outlier, with only about
189 10% of the *M. salemaai* density expected for a lake of this depth. It is not clear why this lake has a low
190 *Mysis* density: it is not extreme in terms area or productivity although it is deeper than the other *Mysis*
191 lakes. Zebra mussel, *Dreissena polymorpha* (Pallas, 1771), arrived in Lough Erne in 1996. The
192 species has impacted the Erne ecosystem, by, for example, reducing plankton abundance (Maguire &
193 Gibson, 2005), with potential impacts on *M. salemaai* densities. However, if zebra mussels had

194 significantly impacted *M. salemaai* a marked difference would be expected in pre- and post-invasion
195 densities: no such shift is apparent in Fig. 3.

196 Two of the largest lakes in Ireland, Loughs Neagh and Erne, show *M. salemaai* population
197 declines. In Lough Neagh densities have dropped from around 300 m⁻³ in 1993, much higher than
198 recorded in other Irish lakes (Table 1), to a more typical density of about 1 m⁻³ in 2012. *Mysis* declines
199 potentially affect on other components of the ecosystem. In particular, *M. salemaai* is an major food
200 source for cold water fish in Lough Neagh (Biggsby, 2000; Kirkwood, 1996; Vaughan, 2009), including
201 the conservationally important glacial relict *Coregonus autumnalis* (Pallas, 1811). Griffiths (2007)
202 concluded that changing temperatures and, to a lesser extent, eutrophication were the factors driving
203 population declines in Lough Neagh between 1994-2005. The absence of a correlation between
204 annual fluctuations in density in the two lakes suggests that other factors in addition to temperature
205 could be involved. The recent discovery of the bloody-red shrimp (*Hemimysis anomala* G. O. Sars,
206 1907) in Lough Erne (Gallagher *et al.*, 2014) may also reduce *M. salemaai* densities in the future by
207 competition, as *Hemimysis anomala* has a higher feeding rate than *M. salemaai* (Dick *et al.*, 2013).

208 If rising temperatures are driving the decline in the Irish *M. salemaai* populations then their
209 long-term survival is in doubt, given the expected warming in Ireland (most models predict rises of 3-
210 4°C) this century (Dunne *et al.*, 2008; Sweeney & Fealy, 2002; Woodward, Quaife & Lomas, 2010).
211 Translocations to cold-water lakes, i.e. to higher elevation water bodies, is a possibility to maintain the
212 species. However, many previous introductions of *M. salemaai* have had deleterious effects on other
213 components of the ecosystem (Nesler & Bergersen, 1991), so this conservation option needs careful
214 consideration.

215

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228 Upper, which Tony Fitzsimons (Aquatic Sciences Research Division, Department of Agriculture for
229 Northern Ireland) subsequently confirmed from his unpublished records. Our thanks to two
230 anonymous referees for helpful comments.

231

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302

303

304 Table 1—Summary features of Irish lakes and estimated spring densities of *Mysis salemaai*

305 populations.

Lake	Area (km ²)	Mean depth (m)	Maximum depth (m)	Altitude (masl)	Catchment	Trophic state	<i>M. salemaai</i> density (number.m ⁻³)	Data source
Allen	33.3	4.5	42	42	Shannon	Oligotrophic	1.55	Penk (2011)
Castlewellan	0.36	6.2	21	120	Carrigs?	Eutrophic	0.94	This study
Corrib	166	12	50	2	Corrib	Oligotrophic	8.20	Penk (2011)
Derg	128	7.6	36	34	Shannon	Mesotrophic	0.36	Penk (2011)
Derravaragh	10.8		24	64	Shannon	Oligotrophic	0.27	Penk (2011)
Erne	110	11.9	62	46	Erne	Mesotrophic	0.12	This study
Garadice	3.8	4.7	17	54	Erne	Oligotrophic	0.27	Penk (2011)
Gowna	11.2	3.8	20	62	Erne	Eutrophic		Penk <i>et al.</i> (2014)
Key	8.7	5.1	22	38	Shannon	Mesotrophic	0.82	Penk (2011)
Macnean Upper	9.5	4.4	23	48	Erne			Fitzsimons (pers. comm.)
Neagh	385	8.9	33	12	Neagh	Eutrophic	1.36	This study
Oughter	11.1	2.2	14	50	Erne	Eutrophic	0.05	Penk (2011)
Ree	99.8	6.2	35	38	Shannon	Mesotrophic	0.27	Penk (2011)
Scolban	0.58	7.8	30	50	Erne	Oligotrophic	0.05	This study

306

307 **Figure legends**

308

309 **Fig. 1 (a) *Mysis salemaai* densities for different vertical haul distances in different lakes. (b)**

310 **Mean *M. salemaai* density as a function of maximum lake depth, after adjusting to a**

311 **standardised vertical haul distance. Lough Erne (light fill point) was omitted from the**

312 **regressions.**

313

314 **Fig. 2—Histograms of lake area and maximum depth for lakes with (dark shading) and without**

315 **(light shading) *Mysis salemaai* populations.**

316

317 **Fig. 3—Temporal trends in mean *Mysis salemaai* density in (a) Lough Neagh and (b) Lough**

318 **Erne.**

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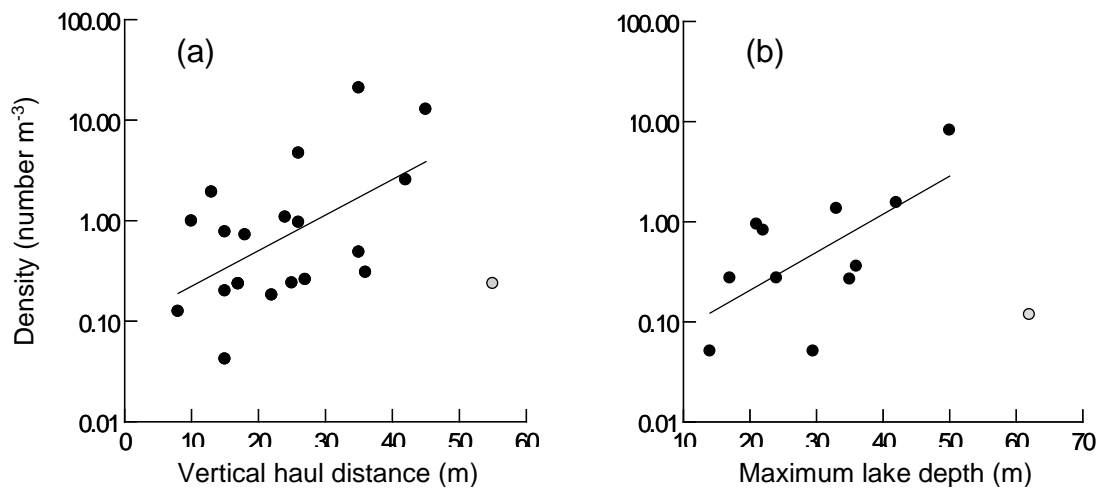


Fig. 1

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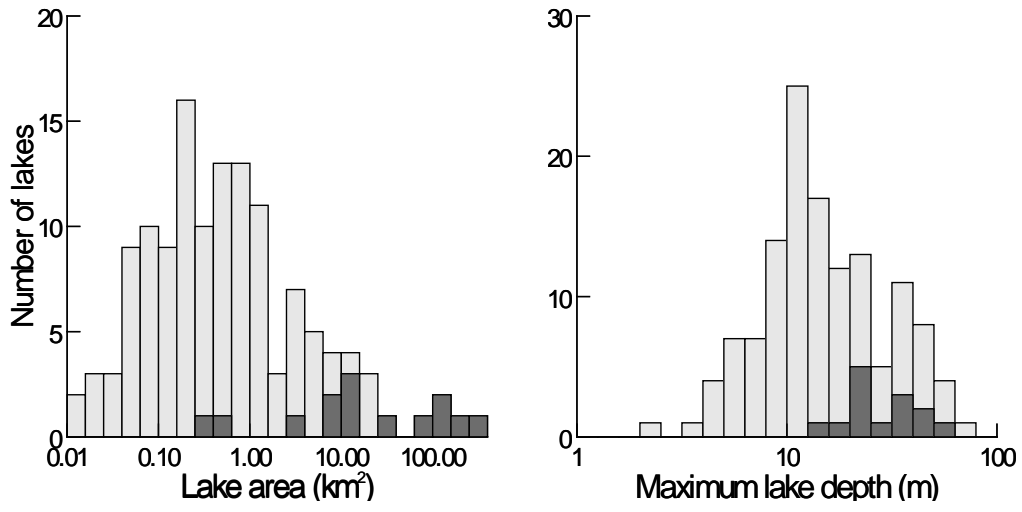


Fig. 2

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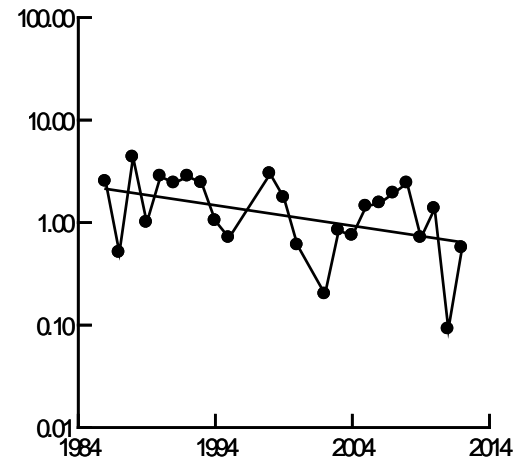
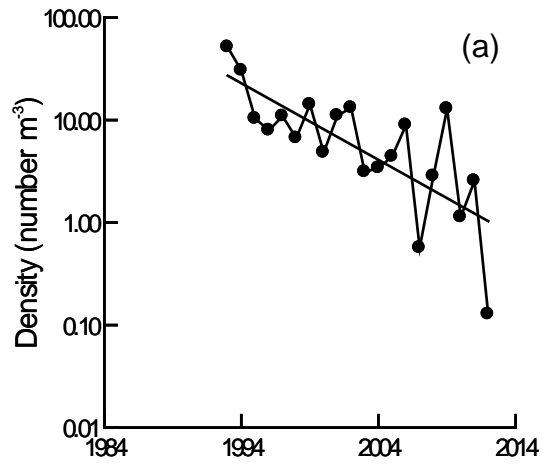


Fig. 3