



**QUEEN'S  
UNIVERSITY  
BELFAST**

## **Mysis salemaai in Ireland: new occurrences and existing population declines**

Griffiths, D., Macintosh, K. A., Forasacco, E., Rippey, B., Vaughan, L., McElarney, Y. R., & Gallagher, K. (2015). Mysis salemaai in Ireland: new occurrences and existing population declines. *Biology and Environment: Proceedings of the Royal Irish Academy*, 115B(1), 59-65. <https://doi.org/10.3318/bioe.2015.06>

### **Published in:**

Biology and Environment: Proceedings of the Royal Irish Academy

### **Document Version:**

Peer reviewed version

### **Queen's University Belfast - Research Portal:**

[Link to publication record in Queen's University Belfast Research Portal](#)

### **Publisher rights**

Copyright 2015 Royal Irish Academy.

### **General rights**

Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

### **Take down policy**

The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact [openaccess@qub.ac.uk](mailto:openaccess@qub.ac.uk).

### **Open Access**

This research has been made openly available by Queen's academics and its Open Research team. We would love to hear how access to this research benefits you. – Share your feedback with us: <http://go.qub.ac.uk/oa-feedback>

1 SHORT COMMUNICATION

2

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

4 **DECLINES**

5

6 David Griffiths <sup>1</sup> Katrina A Macintosh <sup>1,\*</sup> Elena Forasacco <sup>1</sup> Brian Rippey <sup>1</sup> Louise Vaughan <sup>2</sup> Yvonne

7 R. McElarney <sup>2</sup> Kevin Gallagher <sup>2</sup>

8

9 <sup>1</sup> School of Environmental Sciences, University of Ulster, Coleraine, U.K. BT52 1SA

10 <sup>2</sup> Agri-Environment Branch, Agri-Food and Biosciences Institute, Belfast, U.K. BT9 5PX

11

12 \* Corresponding author:

13 E-mail address: ka.macintosh@ulster.ac.uk

14 Tel.: +44 (0) 28 70124426

15 Fax: +44 (0) 28 70124911

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 $\mu$ 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 m<sup>3</sup>).

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<sup>-3</sup>) 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 20<sup>th</sup> 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<sup>-3</sup> in 1993, much higher than  
198 recorded in other Irish lakes (Table 1), to a more typical density of about 1 m<sup>-3</sup> 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, Quaipe & 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

## 216 ACKNOWLEDGEMENTS

217

218 This work was part-financed by the European Union's INTERREG IVA Cross-border Programme  
219 managed by the Special EU Programmes Body under the project "Development of targeted ecological  
220 modelling tools for lake management; DOLMANT" (Ref. No: 002862) and the Department of  
221 Agriculture Northern Ireland. The Lough Neagh and Lough Erne 2005-2012 samples were collected  
222 by the Agri-Food and Biosciences Institute as part of the Environmental Change Network, which is  
223 funded by the Department of Agriculture Northern Ireland. Thanks are also extended to Richard

224 McFaul (Northern Ireland Environment Agency), Sam Roberson (Geological Survey of Northern  
225 Ireland) and Richard Kernohan (Forestry Service Northern Ireland) for information regarding  
226 Castlewellan Lake. Bob Foy (Agri-Environment Branch, Agri-Food and Biosciences Institute) drew our  
227 attention to the introduction of *Mysis* to Castlewellan Lake and its occurrence in Lough Macnean  
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

232 REFERENCES

- 233 Andrew, T.E. & Woodward, E. (1993). Some observations on the populations of *Mysis relicta* in Lough  
234 Neagh. In *Lough Neagh: the ecology of a multipurpose water resource* (eds R.B. Wood &  
235 R.V. Smith), pp. 327-338. Kluwer Academic Publishers, Dordrecht.
- 236 Audzijonyte, A. & Väinölä, R. (2005) Diversity and distributions of circumpolar fresh- and brackish-  
237 water *Mysis* (Crustacea: Mysida): descriptions of *M. relicta* Lovén, 1862, *M. salemaai* n. sp.,  
238 *M. segerstralei* n. sp. and *M. diluviana* n. sp., based on molecular and morphological  
239 characters. *Hydrobiologia*, **544**, 89-141.
- 240 Audzijonyte, A. & Väinölä, R. (2006) Phylogeographic analyses of a circumarctic coastal and a boreal  
241 lacustrine mysid crustacean, and evidence of fast postglacial mtDNA rates. *Molecular*  
242 *Ecology*, **15**, 3287-3301.
- 243 Bigsby, E.J. (2000) *Interactions between macro-invertebrates, fish and diving ducks in Lough Neagh*.  
244 D. Phil. thesis, University of Ulster.
- 245 Brown, J.H. & Kodric-Brown, A. (1977) Turnover rates in insular biogeography: effect of immigration  
246 on extinction. *Ecology*, **58**, 445-449.
- 247 Department of Agriculture Science Service (1980) Fish samples from Castlewellaan Lake report.  
248 Belfast: Department of Agriculture Science Service.
- 249 Dick, J.T.A., Gallagher, K., Avlijas, S., Clarke, H.C., Lewis, S.E., Leung, S., Minchin, D., Caffrey, J.,  
250 Alexander, M.E., Maguire, C., Harrod, C., Reid, N., Haddaway, N.R., Farnsworth, K.D., Penk,  
251 M., & Ricciardi, A. (2013) Ecological impacts of an invasive predator explained and predicted  
252 by comparative functional responses. *Biological Invasions*, **15**, 837-846.
- 253 Duck, R. & Carwardine, J. (2005). Lake hydromorphology: Part 1 Review of existing bathymetric  
254 information for lakes T1 Rep. No. (A7b.1) - 1.0. North South Shared Aquatic Resource (NS  
255 Share).
- 256 Dunne, S., Hanafin, J., Lynch, P., McGrath, R., Nishimura, E., Nolan, P., Ratnam, J.V., Semmler, T.,  
257 Sweeney, C., Varghese, S., & Wang, S. (2008) *Ireland in a warmer world: scientific*  
258 *predictions of the Irish climate in the twenty-first century* Community Climate Change  
259 Consortium for Ireland (C4I), Dublin.

260 Gallagher, K., Rosell, R., Vaughan, L., McElarney, Y.R., Campbell, W., O'Kane, E., & Harrod, C.  
261 (2014) *Hemimysis anomala* (G.O. Sars, 1907) expands its invasive range to Northern Ireland.  
262 *BioInvasions Records*, **3**, in press.

263 Griffiths, D. (2007) Effects of climate change and eutrophication on the glacial relict, *Mysis relicta*, in  
264 Lough Neagh. *Freshwater Biology*, **52**, 1957-1967.

265 Horppila, J., Liljendahl-Nurminen, A., Malinen, T., Salonen, M., Tuomaala, A., Uusitalo, L., & Vinni, M.  
266 (2003) *Mysis relicta* in a eutrophic lake: consequences of obligatory habitat shifts. *Limnology*  
267 *and Oceanography*, **48**, 1214-1222.

268 Hull, E. (1881) *Explanatory memoir to accompany sheets 60,61 and part of 71 of the maps of the*  
269 *Geological Survey of Ireland including the country around Newry, Rathfriland and Rostrevor,*  
270 *in the county of Down; and the Mourne mountains* H. M. S. O., Dublin.

271 Kirkwood, R.C. (1996) *Interactions between fish, Mysis, and zooplankton in Lough Neagh*. D. Phil.,  
272 University of Ulster.

273 Knight, J. (2002) Bedform patterns, subglacial meltwater events, and Late Devensian ice sheet  
274 dynamics in north-central Ireland. *Global and Planetary Change*, **35** 237-253.

275 Maguire, C. & Gibson, C. (2005) Ecological change in Lough Erne: influence of catchment changes  
276 and species invasions. *Freshwater Forum*, **24** 38-58.

277 Ministry of Agriculture for Northern Ireland (1969) *Mysis* introduction to Castlewellan Lake - project  
278 proposal. Ministry of Agriculture for Northern Ireland.

279 Nesler, T.P. & Bergersen, E.P. (1991) Mysids in fisheries: hard lessons in headlong introductions.  
280 *American Fisheries Society Symposium*, **9**, 199 pp.

281 Penk, M., Donohue, I., Récoules, V., & Irvine, K. (2014) Elevated temperatures interact with habitat  
282 quality to undermine survival of ectotherms in climatic refugia. *Diversity and Distributions*, **21**,  
283 200-210.

284 Penk, M.R. (2011) A review of the current distribution of the freshwater opossum shrimp *Mysis*  
285 *salemaai* Audzijonyte and Väinölä, 2005 in Ireland. *Biology & Environment: Proceedings of*  
286 *the Royal Irish Academy*, **111B**, 1-9.

287 Penk, M.R. & Minchin, D. (2014) Seasonal migration of a glacial relict mysid (Crustacea) into the  
288 littoral zone and its co-occurrence with an introduced competitor in Lough Derg (Ireland).  
289 *Hydrobiologia*, **726**, 1-11.

- 290 Sandeman, I.M. & Lasenby, D.C. (1980) The relationships between ambient oxygen concentration,  
291 temperature, body weight, and oxygen consumption for *Mysis relicta* (Malacostraca:  
292 Mysidacea). *Canadian Journal of Zoology*, **58**, 1032-1036.
- 293 Sweeney, J. & Fealy, R. (2002) A preliminary investigation of future climate scenarios for Ireland.  
294 *Biology and Environment: Proceedings of the Royal Irish Academy*, **102B**, 121-128.
- 295 Vaughan, L. (2009) *Trophic modelling of the Lough Neagh ecosystem, Northern Ireland*. Ph.D. thesis,  
296 University of Ulster.
- 297 Wetzel, R.G. (2001) *Limnology: lake and river ecosystems*, 3rd edn. Academic Press, London.
- 298 Wilkinson, L., Blank, G., & Gruber, C. (1996) *Desktop data analysis with SYSTAT* Prentice Hall,  
299 Upper Saddle River, New Jersey.
- 300 Woodward, F.I., Quaife, T., & Lomas, M.R. (2010) Changing climate and the Irish landscape. *Biology*  
301 *and Environment: Proceedings of the Royal Irish Academy*, **110B**, 1-16.

302

303

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

305 populations.

| Lake             | Area<br>(km <sup>2</sup> ) | Mean<br>depth<br>(m) | Maximum<br>depth<br>(m) | Altitude<br>(masl) | Catchment | Trophic state | <i>M. salemaai</i><br>density<br>(number.m <sup>-3</sup> ) | 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><br>(2014)   |
| Key              | 8.7                        | 5.1                  | 22                      | 38                 | Shannon   | Mesotrophic   | 0.82   | Penk (2011)                    |
| Macnean<br>Upper | 9.5                        | 4.4                  | 23                      | 48                 | Erne      |               |  | Fitzsimons<br>(pers.<br>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.**

319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329

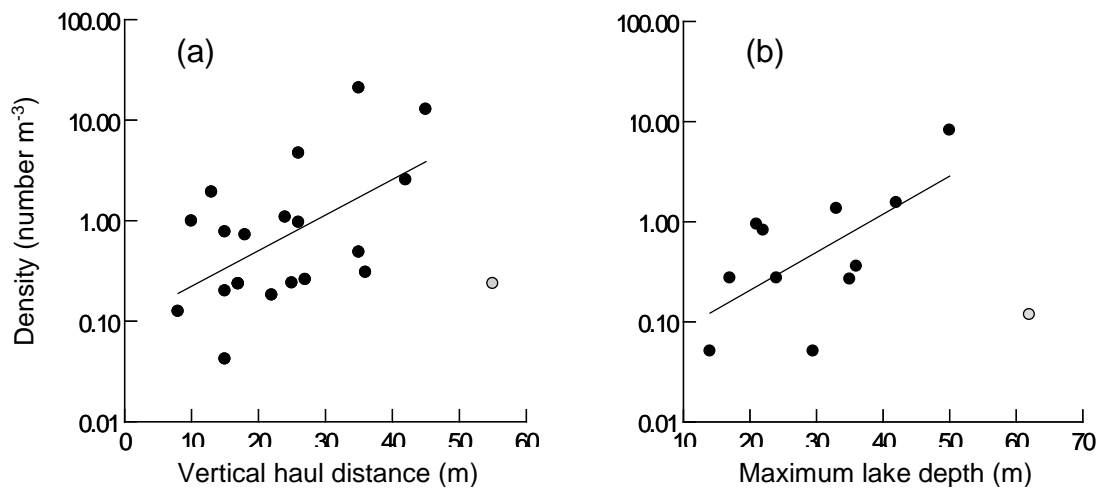


Fig. 1



330  
331  
332  
333  
334  
335  
336  
337  
338  
339

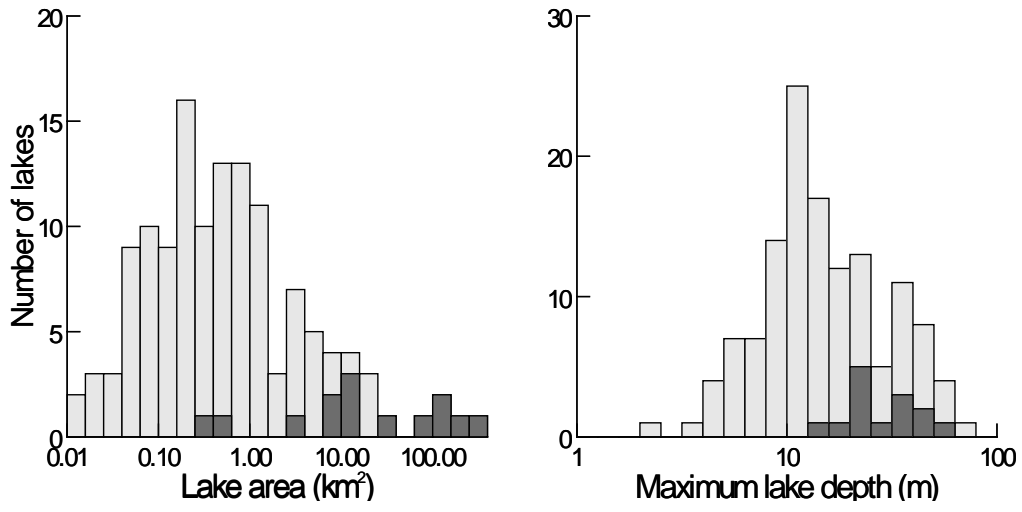


Fig. 2

340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350

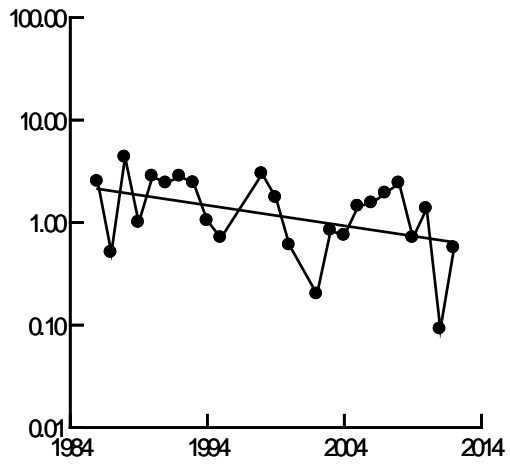
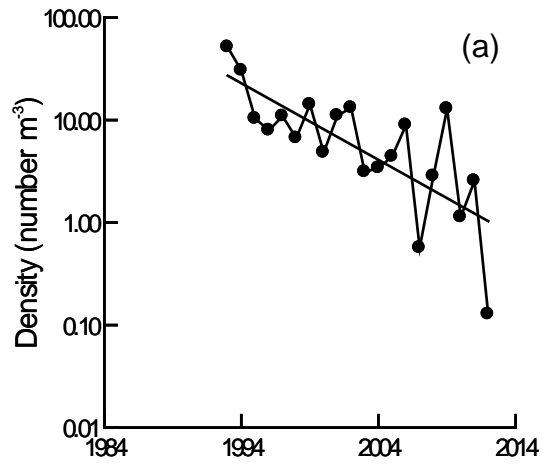


Fig. 3