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Rapid Communication

Non-native freshwater cladoceran *Bosmina coregoni* (Baird, 1857) established on the Pacific coast of North America

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Abstract

The freshwater cladoceran *Bosmina coregoni* (Baird, 1857), native to Eurasia, has established and spread in the Great Lakes region of North America since the 1960s. Here we report the first detection of *B. coregoni* on the Pacific coast of North America, in three geographically distinct locations: the Lower Columbia River Estuary (LCRE), Lake Washington in western Washington state, and the Columbia River Basin in south eastern Washington state. *Bosmina coregoni* was detected on multiple sampling dates in Lake Washington and the LCRE between 2008 and 2012.

Key words: zooplankton; invasive; Washington; freshwater; range expansion

Introduction

Non-indigenous zooplankton have successfully invaded coastal and inland freshwater bodies throughout North America, sometimes with substantial effects on native zooplankton assemblages. For example, zooplankton communities declined in overall taxa richness and abundance after introduction of the predatory cladoceran *Bythotrephes longimanus* to the Laurentian Great Lakes and Canadian Shield lakes (Barbiero and Tuchman 1994; Strecker et al. 2006), and several introduced Asian copepods have impacted northeast Pacific estuaries (Bollens et al. 2002; Cordell et al. 2007; Cordell et al. 2008; Bollens et al. 2012).

The cladoceran *Bosmina coregoni,* common in its native Eurasia, has invaded and established in freshwater lakes throughout eastern North America since the 1960s (Deevey and Deevey 1971; Lieder 1991; Suchy et al. 2010). Genetic comparisons of endemic European and invasive North American populations reveal multiple founding events within the Great Lakes, likely via ship ballast water (Lieder 1991), and subsequent dispersal to surrounding inland lakes (Demelo and Hebert 1994). Until now this species has not been reported on the Pacific coast of North America, but has been detected as far west as Lake Winnipeg and Missouri (Suchy et al. 2010; Mabee 1998).

Bosmina coregoni's effects on native zooplankton and freshwater food webs have not been explicitly studied. *Bosmina coregoni*'s life history traits and herbivorous feeding mode are likely to be similar to other bosminids, though species-level differences have not been examined. Here we report the presence of *B. coregoni* in three geographically distinct freshwater locations on the west coast: the Lower Columbia River Estuary (LCRE), Lake Washington in western Washington state, and the Columbia River Basin in south-eastern Washington state.

Methods

Bosmina coregoni specimens were collected through three separate monitoring and research projects (see Figure 1 for locations). The first was a multi-year field study of the planktonic

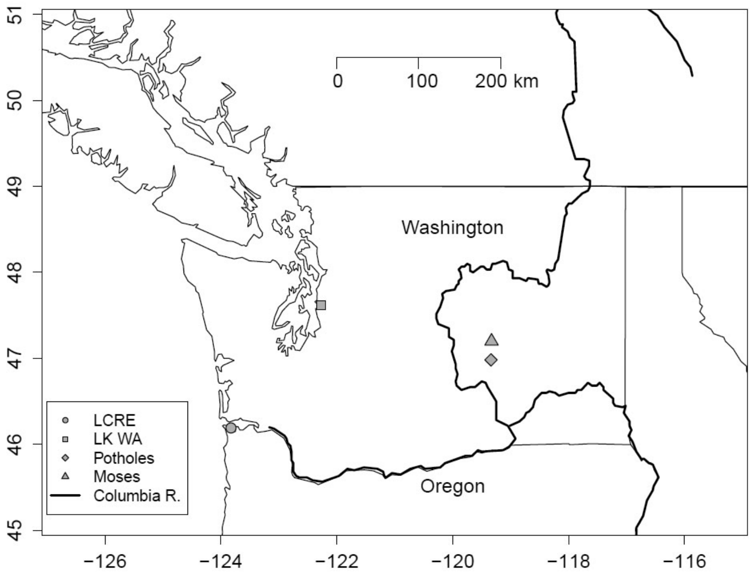


Figure 1. Recorded locations for *Bosmina coregoni* in the Pacific Northwest of the United States (2008–2012) (See Appendix 1 for details).

community in the LCRE. Zooplankton were sampled monthly from a dock near Astoria, Oregon, USA, beginning in January 2005. The dock is located 20 km upstream of the river's mouth and extends 40 m from shore. Triplicate vertical tows with a 0.5-m mouth diameter, 73-µm mesh net equipped with a flow meter were used to collect zooplankton samples. Water column depth during sampling varied between 4.0 and 6.5 m, and tows were made from 0.5 m above the bottom to the water surface. Samples were preserved in 5% buffered formalin. Zooplankton were counted and identified using a dissecting microscope at 25× magnification. The LCRE zooplankton community is currently dominated by a mix of native and non-native copepods, including *Eurytemora affinis*, *Diacyclops thomasi*, *Pseudodiaptomus forbesi*, *Limnoithona tetraspina*, and *Sinocalanus doerrii* (Bollens et al. 2012).

Bosmina coregoni specimens were also collected as part of the long-term monitoring of Lake Washington that began in 1960 and continues to the present. Lake Washington is a large urban lake located at the eastern edge of Seattle, Washington, USA. The lake is 32.2 km long, an average of 2.5 km wide, and has a maximum depth of 64 m. It is used for various recreational purposes, and has two tributaries, the Cedar River at the southern end, and the smaller Sammamish River at the northern end. Lake Washington has been sampled bimonthly or monthly since 1960. The lake's zooplankton fauna is currently dominated by several *Daphnia* and *Bosmina* species, as well as the copepods *Diacyclops thomasi* (Forbes) and *Skistodiaptomus reighardi* (Litt, unpublished data). Zooplankton sampling and processing were done at three representative stations in the lake: Madison Park (MP), Arrowhead Point (AHP), and South of Southend (SSE), according to the methods of Edmondson and Litt (1982). Zooplankton were sampled every 1–3 weeks by taking oblique tows using a closing Clarke-Bumpus sampler equipped with a 73 and 130 µm nylon mesh net and flow meter. Zooplankton samples were preserved in 95% ethanol and counted (Edmondson and Litt 1982). The body lengths of three *Bosmina* and three *Daphnia* species from five 2011 samples (June-October) were measured, and differences in mean body lengths among taxa were tested for statistical significance using Welch's t-test for unequal variances.

Finally, *B. coregoni* was detected in samples collected in August 2012 as part of a limnological survey of 35 lakes in the Columbia River Basin in south-east Washington state. *Bosmina coregoni* was detected in Potholes Reservoir (maximum depth 9.7 m) and the adjacent Canal #1, and Moses Lake (10.2 m). Zooplankton sampling consisted of one open vertical net haul at the deepest attainable point in the water body using an 80 µm, 30 cm diameter zooplankton net. All zooplankton samples were preserved in 70% ethanol. Samples were examined under a dissecting microscope for species identification and counted for relative species abundances.

Figure 2. *Bosmina coregoni* collected from Lake Washington in 2011: A - female; B – male. Photograph by JRC.

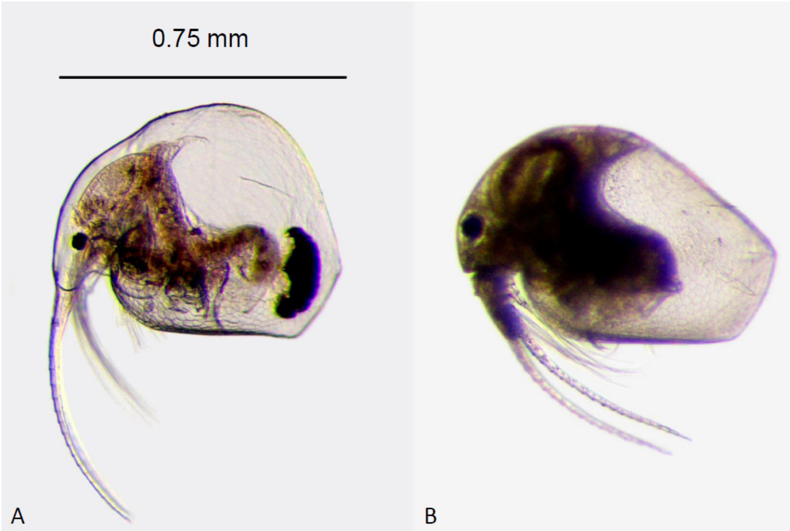
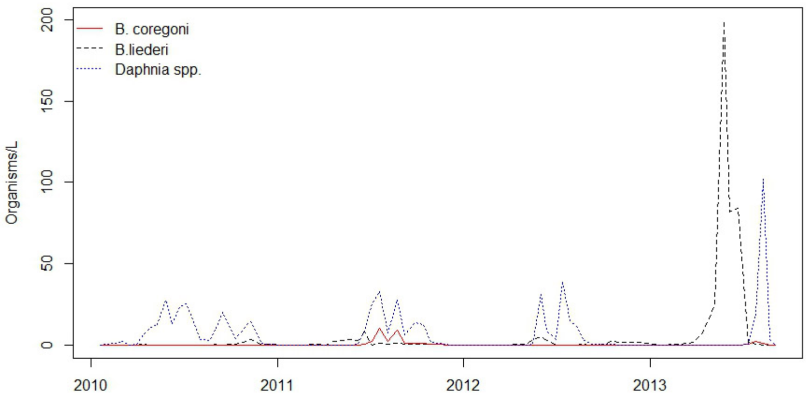


Figure 3. Densities of *B. coregoni* and co-occuring cladoceran species (organisms L^{-1}) in samples collected from Lake Washington (2009–2013). Samples were collected from MP station, at 0–10 m depth.



Zooplankton were identified as *Bosmina coregoni* from morphological characters by Arni Litt. Distinguishing morphological features of *B. coregoni* include the complete lack of a mucron, extremely long antennules, the presence of only proximal pecten on the post abdominal claw, and the location of the sensory bristle near the tip of the rostrum (Kotov et al. 2009; see Figure 2). However, the carapace and rostrum may vary in form, therefore male morphology and genetic markers are required for final taxonomic confirmation (Kotov et al. 2009). Genetic analysis of males collected in Lake Washington was performed by Dr. Alexey A. Kotov of the A. N. Severtsov Institute of Ecology and Evolution, Moscow, Russia and by Derek Taylor of the State University of New York at Buffalo, to confirm species identification.

Results

LCRE

Bosmina coregoni was first detected in LCRE samples on November 22, 2008 and occurred regularly in samples through 2011. Maximum density occurred on July 21, 2009 at 0.123 organisms L^{-1}. *Bosmina coregoni* was present at low density relative to other cladocerans in LCRE samples (Bollens, unpublished data).

Lake Washington

Bosmina coregoni was not detected in monthly samples collected between 1960 and 2010 in Lake Washington. *Bosmina coregoni* was first detected in June 2011 and was present on each of

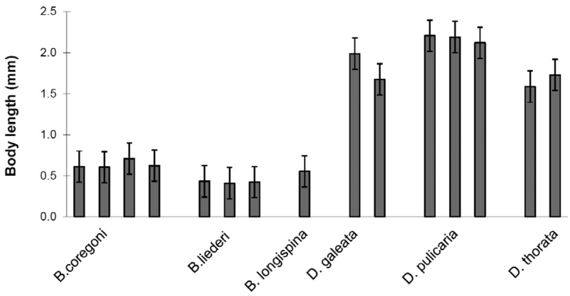


Figure 4. Mean body lengths (mm) of *Bosmina* and *Daphnia* spp. collected from Lake Washington between June and October 2011. Multiple bars per species correspond to samples collected on different dates. Error bars denote standard deviations.

13 sampling dates from June 8, 2011 to December 2, 2011 (see Figure 3), occurring with a maximum density of 10.52 organisms L^{-1} at AHP on July 19, 2011 (0–10 meters depth). Males were present in samples from MP on two dates in October 2011, at densities between 0.0–0.039 organisms L^{-1}, and at depths below 10 meters. *Bosmina coregoni* was not detected in samples collected in 2012 except for one female present in an April sample and a few individuals in November and December at densities of less than 0.03 organisms L^{-1}. In 2013, *B. coregoni* re-occurred with a maximum density of 2.091 organisms L^{-1} in July. Mean body size of mature female *B. coregoni* (n=85) was 0.587 mm, significantly larger than *Bosmina liederi* females (n=67; mean size 0.421 mm; $p<0.001$, df=111) and *Bosmina longispina* females (n=16; 0.553 mm; $p=0.046$, df=48), but significantly smaller than *Daphnia galeata* females (n=26; 1.830 mm; $p<0.001$, df=37), *Daphnia pulicaria* females (n=67; 2.171 mm; $p<0.001$, df=119), or *Daphnia thorata* females (n=39; 1.656 mm; $p<0.001$, df=84) (see Figure 4). All of these species co-occurred in 2011 samples.

Eastern Washington

Bosmina coregoni was detected in Potholes Reservoir and the adjacent Canal #1, and Moses Lake in eastern Washington state in August 2012. *B. coregoni* was the the most numerically abundant species in samples from all sites. Mature *B. coregoni* females made up 36% of the mesozooplankton in the sample from Moses Lake (excluding rotifers and immature stages), and the copepod *Mesocyclops edax* was the second most abundant species, making up 31% of the sample. *Bosmina coregoni* (88%) and *M. edax* (15%) were the most abundant species present in the sample from Potholes Reservoir.

Discussion

While we documented the presence of *B. coregoni* only in three freshwater locations along the west coast of North America, this species' prolific invasion history in the Great Lakes region suggests its current range may extend far beyond our sampling area. An exact invasion mechanism for this species in our study area may never be established, since cladocerans and their resting eggs can be transported in a variety of ways, including migratory birds, recreational boats, and direct hydrological connections (Figuerola and Green 2002; Havel and Medley 2006). The presence of this species in non-coastal eastern Washington suggests between-lake dispersal mechanisms such as recreational boating or migrating waterfowl, and suggests the possibility that *B. coregoni*'s range has expanded across the continent in this fashion.

No studies from the Great Lakes region have directly addressed the ecological impacts of *B. coregoni* introduction to new aquatic habitats. In sporadically monitored lakes, realization of its presence can trail initial invasion by decades (Suchy and Hann 2007). Lake Washington's zooplankton community, monitored continuously since 1960 (Edmondson et al. 2003; Hampton and Schindler 2006), has undergone substantial shifts in species composition and abundance, often in clear response to changing environmental factors (Edmondson and Litt 1982). The addition of *B. coregoni* may shift population dynamics within the zooplankton community, since *B. coregoni* is larger than co-occurring bosminids *B. liederi* and *B. longispina* but likely too small to fall prey to juvenile sockeye salmon or other planktivorous fish (Scheuerell et al. 2005).

Though *B. coregoni* did not reoccur in significant abundance in Lake Washington samples during the years following its initial invasion, overall *Bosmina* density was also low, and its reappearance is likely. Sediment cores taken from Lake of the Woods, Ontario showed that *B. coregoni* can persist at low density relative to native *Bosmina* for decades after an initial invasion event (Suchy and Hann 2007). Previous literature indicates that *B. coregoni* mainly occurs in inland freshwater habitats, but this species' multi-year, low density persistence in the LCRE implies either its successful establishment in an estuarine environment, or repeated introductions. While the sampling site in the LCRE does periodically experience saline conditions (Bollens et al. 2012), this may not necessarily represent an expansion of *B. coregoni*'s abiotic range, as zooplankton could have drifted from freshwater locations upstream. Unlike in Lake Washington or the LCRE, *B. coregoni* appears to be numerically dominant in the Eastern Washington lakes sampled; there is currently insufficient knowledge of the biotic and abiotic characteristics of these lakes to determine why *B. coregoni* has become so abundant there. Further sampling throughout the Pacific Northwest will likely expand its known range and elucidate its interactions with native freshwater communities. Future comparisons between Lake Washington and the LCRE will especially aid these efforts, as they are sampled regularly, overlap considerably in their zooplankton communities, but differ substantially in physical and chemical characteristics.

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References

Barbiero RP, Tuchman ML (1994) Changes in the crustacean communities of Lakes Michigan, Huron, and Erie following the invasion of the predatory cladoceran *Bythotrephes longimanus*. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2111–2125, http://dx.doi.org/10.1139/f04-149

Bollens SM, Cordell JR, Avent S, Hooff R (2002) Invasive Zooplankton: A brief review, plus two case studies from the northeast Pacific Ocean. *Hydrobiologia* 480: 87–110, http://dx.doi.org/10.1023/A:1021233018533

Bollens SM, Breckenridge J, Cordell JR, Rollwagen-Bollens GC, Kalata O (2012) Invasive copepods in the lower Columbia River estuary: Seasonal abundance, co-occurrence and potential competition with native copepods. *Aquatic Invasions* 7: 101–109, http://dx.doi.org/10.3391/ai.2012.7.1.011

Cordell JR, Bollens SM, Draheim R, Sytsma M (2008) Asian copepods on the move: recent invasions in the Columbia–Snake River system, USA. *ICES Journal of Marine Science* 65: 753–758, http://dx.doi.org/10.1093/icesjms/fsm195

Cordell JR, Rassmussen M, Bollens SM (2007) Biology of the invasive copepod *Pseudodiaptomus inopinus* in a northeast Pacific estuary. *Marine Ecology Progress Series* 333: 213–227, http://dx.doi.org/10.3354/meps333213

Deevey ES, Deevey GB (1971) The American species of *Eubosmina seligo* (Crustacea, Cladocera). *Limnology and Oceanography* 16: 201–218, http://dx.doi.org/10.4319/lo.1971.16.2.0201

De Melo R, Hebert PDN (1994) Founder effects and geographical variation in the invading cladoceran *Bosmina (Eubosmina) coregoni* Baird 1857 in North America. *Heredity* 73: 490–499, http://dx.doi.org/10.1038/hdy.1994.147

Edmondson WT, Litt AH (1982) *Daphnia* in Lake Washington. *Limnology and Oceanography* 27: 272–293, http://dx.doi.org/10.4319/lo.1982.27.2.0272

Edmondson WT, Abella SE, Lehman JT (2003) Phytoplankton in Lake Washington: long-term changes 1950-1999. *Archiv fur Hydrobiologie. Supplement volumes, Monographic studies* 139: 275–326

Figuerola J, Green AJ (2002) Dispersal of aquatic organisms by waterbirds: a review of past research and priorities for future studies. *Freshwater biology* 47: 483–494, http://dx.doi.org/10.1046/j.1365-2427.2002.00829.x

Hampton SE, Schindler DE (2006) Empirical evaluation of observation scale effects in community time series. *Oikos* 113: 424–439, http://dx.doi.org/10.1111/j.2006.0030-1299.14643.x

Havel JE, Medley KA (2006) Biological invasions across spatial scales: intercontinental, regional, and local dispersal of cladoceran zooplankton. *Biological Invasions* 8: 459–473, http://dx.doi.org/10.1007/s10530-005-6410-4

Kotov AA, Ishida S, Taylor DJ (2009) Revision of the genus *Bosmina* Baird, 1845 (Cladocera: Bosminidae), based on evidence from male morphological characters and molecular phylogenies. *Zoological Journal of the Linnean Society* 156: 1–51, http://dx.doi.org/10.1111/j.1096-3642.2008.00475.x

Lieder U (1991) The *Bosmina kessleri*-like morphotype of *Eubosmina* in Lake Muskoka, Ontario, Canada, as putative interspecific hybrids. *Hydrobiologia* 225: 71–80, http://dx.doi.org/10.1007/BF00028386

Mabee WR (1988) A note on the occurrence of *Bosmina (Eubosmina) coregoni* (Crustacea, Cladocera) in Missouri: a new record and range extension. *Southwestern Naturalist* 43: 95–96

Scheuerell JM, Schindler DE, Scheuerell MD, Fresh KL, Sibley TH, Litt AH, Shepherd JH (2005) Temporal dynamics in foraging behavior of a pelagic predator. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2494–2501, http://dx.doi.org/10.1139/f05-164

Strecker AL, Arnott SE, Yan ND, Girard R (2006) Variation in response of crustacean zooplankton species richness and composition to the invasive predator *Bythotrephes longimanus*. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 2126–2136, http://dx.doi.org/10.1139/f06-105

Suchy KD, Hann BJ (2007) Using microfossil remains in lake sediments to examine the invasion of *Eubosmina coregoni* (Cladocera, Bosminidae) in Lake of the Woods, Ontario, Canada. *Journal of Great Lakes Research* 33: 867–874, http://dx.doi.org/10.3394/0380-1330(2007)33[867:UMRILS]2.0.CO;2

Suchy KD, Salki A, Hann BJ (2010) Investigating the invasion of the nonindigenous zooplankter, *Eubosmina coregoni*, in Lake Winnipeg, Manitoba, Canada. *Journal of Great Lakes Research* 36: 159–166,http://dx.doi.org/10.1016/j.jglr.2009.12.004

Supplementary material

The following supplementary material is available for this article:

Appendix 1. Records of *Bosmina coregoni* detection in the Pacific Northwest of the United States.

Appendix 1. Records of *Bosmina coregoni* detection in the Pacific Northwest of the United States.

Location	Record coordinates		Record dates	Maximum densities of *B. coregoni* in samples (organisms L^{-1})
	Latitude	Longitude		
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 November 2008	0.001333
Lower Columbia River Estuary, OR	46.190278	-123.824444	23 April 2009	0.016667
Lower Columbia River Estuary, OR	46.190278	-123.824444	21 July 2009	0.123333
Lower Columbia River Estuary, OR	46.190278	-123.824444	26 October 2009	0.000333
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 December 2009	0.000333
Lower Columbia River Estuary, OR	46.190278	-123.824444	23 March 2010	0.005
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 April 2010	0.091667
Lower Columbia River Estuary, OR	46.190278	-123.824444	20 May 2010	0.085
Lower Columbia River Estuary, OR	46.190278	-123.824444	21 June 2010	0.000667
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 July 2010	0.000667
Lower Columbia River Estuary, OR	46.190278	-123.824444	24 August 2010	0.045
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 September 2010	0.000333
Lower Columbia River Estuary, OR	46.190278	-123.824444	23 October 2010	0.000333
Lower Columbia River Estuary, OR	46.190278	-123.824444	24 November 2010	0.016333
Lower Columbia River Estuary, OR	46.190278	-123.824444	21 January 2011	0.002
Lower Columbia River Estuary, OR	46.190278	-123.824444	23 February 2011	0.001
Lower Columbia River Estuary, OR	46.190278	-123.824444	22 March 2011	0.003
Lake Washington, WA	47.650000	-122.266667	8 June 2011	0.029716
Lake Washington, WA	47.650000	-122.266667	21 June 2011	0.300104
Lake Washington, WA	47.650000	-122.266667	5 July 2011	2.431315
Lake Washington, WA	47.650000	-122.266667	19 July 2011	10.31256
Lake Washington, WA	47.650000	-122.266667	5 August 2011	1.962684
Lake Washington, WA	47.650000	-122.266667	24 August 2011	8.845455
Lake Washington, WA	47.650000	-122.266667	8 September 2011	0.882
Lake Washington, WA	47.650000	-122.266667	27 September 2011	1.038
Lake Washington, WA	47.650000	-122.266667	14 October 2011	0.833594
Lake Washington, WA	47.650000	-122.266667	28 October 2011	0.445373
Lake Washington, WA	47.650000	-122.266667	15 November 2011	0.390747
Lake Washington, WA	47.650000	-122.266667	29 November 2011	0.045014
Lake Washington, WA	47.650000	-122.266667	18 April 2012	0.022636
Lake Washington, WA	47.650000	-122.266667	13 December 2012	0.004
Lake Washington, WA	47.650000	-122.266667	21 June 2013	0.081
Lake Washington, WA	47.650000	-122.266667	12 July 2013	0.279927
Lake Washington, WA	47.650000	-122.266667	26 July 2013	2.091489
Lake Washington, WA	47.650000	-122.266667	9 August 2013	0.980555
Lake Washington, WA	47.650000	-122.266667	23 August 2013	0.093499
Potholes Reservoir, WA	46.982952	-119.339190	30 August 2012	NA
Moses Lake, WA	47.073184	-119.330385	26 August 2012	NA