Journal of Great Lakes Research 38 (2012) 58–67

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

The life history characteristics, growth and density of *Mysis diluviana* in Lake Pend Oreille, Idaho, USA

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ARTICLE INFO

Article history:
Received 27 November 2010
Accepted 17 May 2011
Available online 27 August 2011

Communicated by Ora Johannsson

Keywords:
Mysids
Opossum shrimp
Lake management
Reproduction

ABSTRACT

Application of management plans for lakes and fisheries, such as the addition of nutrients to increase lake productivity or the removal of non-natives, requires that we understand the biology and ecology of the biota present in those ecosystems. To understand the biology of a non-native freshwater shrimp, *Mysis diluviana*, and provide information for management of it in Lake Pend Oreille, a large (382 km^2) and deep (351 m max depth) lake in northern Idaho, USA, we determined its life history characteristics, estimated growth rates, quantified seasonal density and calculated its production at two widely separated sites. *M. diluviana* required 2 years to reach maturity; reproduction took place from September to October, and young were released between May and June. However, some gravid females and newly released young were observed year-round. Growth rates were higher in summer (0.037 ± 0.004 mm/day) compared to winter (0.023 ± 0.003 mm/day). Density varied from 56 to 2471 individuals/m^2, while production ranged between 2.18 and 3.12 g dry mass/m^2/yr. These data can be used by managers of the Lake Pend Oreille ecosystem to optimize management strategies that increase kokanee production such as timing the potential application of nutrients, and/or the removal of mysids. Furthermore, we expand the knowledge of *M. diluviana* in large and deep lakes outside its native range.

Introduction

Mysis diluviana, previously *Mysis relicta* (Audzijonytë and Väinölä, 2005), is an omnivorous freshwater shrimp that undergoes diel vertical migration (DVM) and plays an important role in the transfer of energy and matter in aquatic ecosystems. Typically, mysids are suprabenthic during the day (Beeton and Bowers, 1982; Lasenby and Sherman, 1991; Levy, 1991; Rudstam et al., 1989) feeding on detritus, sediment, and in some lakes, zooplankton (Johannsson et al., 2001). At night, mysids ascend to surface waters where they prey on zooplankton (Cooper and Goldman, 1980; Grossnickle, 1982) and other food items in the pelagic zone. During DVM, mysids transfer nutrients associated with the food consumed between pelagic and hypolimnetic zones via egestion and excretion (Van Duyn-Henderson and Lasenby, 1986). Because of its high lipid content (Adare and Lasenby, 1994), large size (1–2 cm) relative to other zooplankton, and its importance in the diet of fish (Isaac, 2010; Lasenby et al., 1986; Wells and Beeton, 1963), lake managers widely introduced *M. diluviana* to lakes in Scandinavia and across the Pacific Northwest in North America as a forage item to increase the production of fish (Lasenby et al., 1986; Northcote, 1991). Although some introductions were successful in producing large and plentiful fish (e.g., Sparrow et al., 1964), the majority of introductions resulted in the collapse of target fisheries and altered entire ecosystems (Beattie and Clancey, 1991; Ellis et al., 2011; Richards et al., 1991; Rieman and Falter, 1981).

In North America, *M. diluviana* was introduced to lakes in an attempt to increase kokanee production by replicating results from Kootenay Lake, British Columbia, Canada, where the introduction of mysids in 1949 as supplementary food for Kamloops rainbow trout led instead to trophy kokanee in the 1950's (Martin and Northcote, 1991; Sparrow et al., 1964). Consequently, *Mysis* was introduced to some of the largest and deepest lakes such as Lake Tahoe, CA, Lake Chelan, WA, and Lake Pend Oreille (LPO hereafter), ID, outside of the Great Lakes basin, which led to the collapse of fisheries and whole ecosystems (Ellis et al., 2011; Richards et al., 1991; Rieman and Falter, 1981). In LPO 50,000 to 300,000 mysids from Waterton, AB, and Kootenay Lakes, BC, Canada were introduced each year from 1966 to 1970, (Rieman and Falter, 1981), which established a self-sustaining population by 1972. Densities reached a maximum of 1980 mysids/m^2 in June of 1978 (Rieman and Falter, 1981). Since then, mysid densities have been variable, with a low of 300 mysids/m^2 and recent increases to approximately 1000 mysids/m^2 (A. Dux, pers. comm., IDFG Principal Fisheries Biologist, 2010; Maiolie et al., 2006). Similar to other lakes where mysids were introduced (Lasenby et al., 1986), kokanee density in LPO declined rapidly and precipitously (Bowler, 1982; Bowles et al., 1991; Rieman and Bowler 1980), culminating in closure of the commercial and recreational fisheries.

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doi:10.1016/j.jglr.2011.07.010

The exact cause for the decline of kokanee in LPO is uncertain, as a combination of factors including alteration in the winter drawdown (Maiolie et al., 2006); an increase in the abundance of lake trout (Hansen et al., 2008); and the establishment of mysids occurred nearly simultaneously (Rieman and Bowler, 1980; Rieman and Falter, 1981). In general, the introduction of mysids delays the appearance of abundant cladocerans in spring, and reduces their overall density (Ashley, et al., 1997; Ellis et al., 2011; Rieman and Falter 1981). Thus, it is likely that mysids outcompete fish fry for zooplankton prey in LPO. Currently, lake management goals for LPO include the removal of lake trout (*Salvelinus namaycush*) and rainbow trout (*Onchorhynchus mykiss*) to reduce predation on kokanee (*Onchorhynchus nerka*) and recover the population of adult kokanee (*O. nerka*). The objective here is to 1) provide a food source for bull trout (*Salvelinus confluentus*), which is listed as threatened under the US Endangered Species Act of 1973, and; 2) to re-establish a fishery for the public. Also under consideration is action geared toward ameliorating the negative effects of mysids. However, to choose and effectively target such management requires that managers understand the lake-specific ecology of mysids in LPO.

Phenotypic plasticity is an important characteristic for the success of species in non-native habitats (Stearns, 1992). Research of the life history of *M. diluviana* in its natural range including the Great Lakes basin, (Johannsson, 1992; Kjellberg et al., 1991; Pothoven et al., 2000; Scharf and Koschel, 2004) and in introduced lakes such as LPO, ID, Lake Tahoe, CA, Flathead Lake, MT, and Kootenay Lake, BC, Canada (Chess and Stanford, 1998; Chipps and Bennett, 2000; Morgan, 1980, 1981; Smokorowski, 1998) has shown that it is highly plastic and related to lake productivity. For example, mysids from a single source introduced to Flathead Lake require 1 year to reach maturity because of abundant cladoceran prey (Chess and Stanford, 1998), while in Lake Tahoe, an ultra-oligotrophic system, they require between 2 and 4 years to reach maturity, depending on location in the lake (Morgan, 1980, 1981). These differences in generation times produce patterns in seasonal growth and reproductive timing, and ultimately energy demand. Such patterns offer potential insights for lake managers to implement actions specifically targeted at mysids.

The management of lakes to reduce the negative impact of mysids currently entails two major approaches; whole-lake nutrient enhancement or reducing the density of mysids via fishing. In Kootenay Lake of southern B.C., Canada, managers employed a nutrient enhancement program to stimulate a bottom-up trophic cascade and ensure a sufficient density of desirable zooplankton prey to sustain fish fry (Ashley et al., 1997, Schindler et al., 2009). The intentional application of nutrients to entire lakes is counter to nutrient abatement programs and federal statues such as the US Clean Water Act promulgated in response to the general eutrophication of aquatic ecosystems. However, Kootenay Lake underwent a series of inflow modifications which severely reduced nutrient delivery to the lake. This decrease in nutrient inputs combined with the presence of mysids reduced zooplankton food for fish fry (Ashley et al. 1997). In contrast, in Okanagan Lake, B.C., managers opted to reduce the density of mysids via fishing (Andrusak et al., 2006) to avoid potential conflicts with generalized basin-wide nutrient abatement strategies (e.g., TSWQC, 2001). Given the complex interactions between mysid ecology, response to food availability, lake productivity and density (Smokorowski, 1998), managers must know lake-specific characteristics of the mysid population to evaluate and select an effective management strategy.

Our study was designed to examine the life history characteristics of the non-native population of *M. diluviana* in LPO to help identify possible management strategies that reduce the effects of mysids on kokanee salmon and increase the population of bull trout. Specific objectives were to 1) determine and compare the life cycle of *M. diluviana* at two widely separated sites of different depth to examine possible within-lake differences; 2) calculate seasonal growth rates; 3) determine the seasonal variability in mysid density and compare these among sites and to other studies; and 4) calculate the production of *M. diluviana*. Finally, we provide suggestions for potential management strategies to ameliorate the negative effects of mysids to aid in the recovery of kokanee in LPO.

Methods

Study site

Lake Pend Oreille, is a large (380 km^2) and deep (351 m maximum depth, 164 m mean depth) temperate oligotrophic (total phosphorous -TP-<7 μg/L, Chlorophyll *a* -Chl *a*-<5.5 mg/m^2) lake, located in the panhandle of northern Idaho, USA (Falter and Ingman, 2003). The main inflow to the lake is the Clark Fork River which enters LPO from Montana. The lake outlet forms the Pend Oreille River which flows west into Washington (Fig. 1). The lake can be separated into two major basins; the northern basin located to the north and west of the Clark Fork delta which is shallower (<200 m max. depth) than the southern basin located south of the Clark Fork delta (>250 m max. depth; Fig. 1). The water level of LPO is controlled at the outlet by Albeni Falls Dam for flood control, power production and flow augmentation to the Columbia River System. Typically the lake level is maintained at high water pool from June to September, while in the winter it is dropped by up to 3 m (Maiolie et al., 2006). In general, the lake thermally stratifies from late June to September to a depth of approximately 23 m (Caldwell 2010; Falter and Ingman, 2003). Native fish in LPO include bull trout (*S. confluentus),* westslope cutthroat trout (*Oncorhynchus clarki lewisi),* and mountain whitefish (*Prosopium williamsoni*). Kokanee salmon (*O. nerka*), rainbow trout (*O. mykiss*), lake trout (*S. namaycush*), lake whitefish (*Coregonus clupeaformis*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and walleye (*Sander vitreus*) are all non-natives that have become established in the lake through either intentional or accidental introduction.

We sampled one site in each of the northern (North Site; 161 m; N48°13.000′ W116°20.687′; Fig. 1) and southern basin (South Site; 287 m; N47°58.035′ W116°29.218′; Fig. 1). This selection was intentional to examine if the life history of mysids varied between the shallower northern basin and the deeper southern basin.

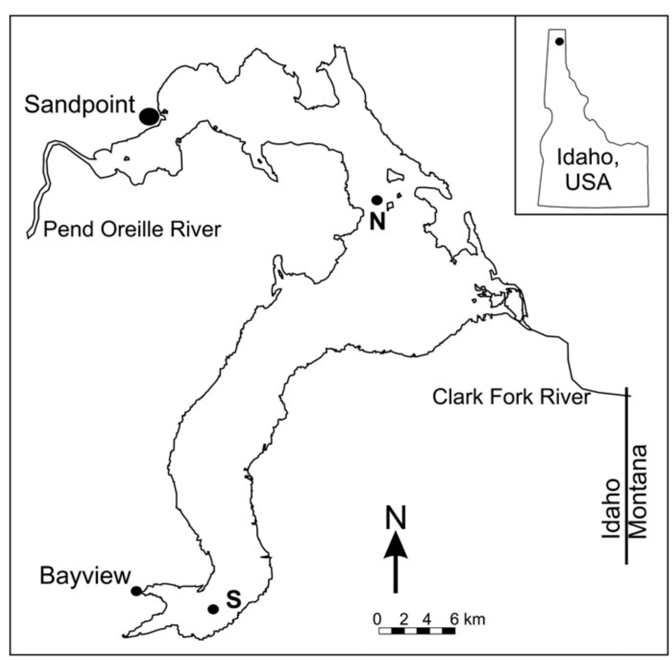

Fig. 1. Map of Lake Pend Oreille, showing its location in Idaho, USA, and the north (N) and south (S) sampling sites. See Fields et al. (1996) for bathymetry.