Irrigation canals represent a bioenergetic sink for primary consumers

Keywords: mollusk entrainment, biodiversity, energy transfer, population dynamics, Idaho

ABSTRACT

The conservation and management of western North American freshwater mollusks has been the focus of considerable attention as western populations grow; challenging conservation and management efforts. Managing these important freshwater resources effectively requires information regarding the natural history of molluscan populations and communities. We investigated mortality factors influencing the community of freshwater mollusks in the Boise River, Idaho, USA. Specifically we conducted a systematic survey for mollusks entrained in 1km of the Phyllis Canal in south-western Idaho; a major irrigation canal diverting water from the Boise River. Results demonstrate that ten species from three families of freshwater mollusks were entrained in the Phyllis Canal in the 2013 irrigation season. An estimated 18 Kg of freshwater mollusks were entrained in the 78 Km canal. *Stagnicola elodes* constituted 85% of the 483 individuals collected resulting in an uneven estimation for Simpson's *D* and *E*. Implications of the current work are discussed and recommendations for future work are advanced.

INTRODUCTION

The conservation and management of western North American freshwater mollusks has been the focus of considerable attention recently (Lysne and Krouse 2011, Liu and Hershler 2012, Johnson et al. 2013, Hershler et al. 2014). As western populations grow the pressures on freshwater ecosystems will grow commensurately (Hershler et al. 2014); challenging conservation and management efforts. For example, in Idaho approximately 20 million gallons of surface water are diverted each day (USGS 2014) through concrete or earthen irrigation canals to support nearly four million acres of land in agricultural production (Niebling 1997). Diverting streamflows for irrigation impedes the movement of organisms (Vörösmarty *et al.* 2010), reduces riverine habitat (Vörösmarty *et al.* 2010), alters the natural hydrologic cycle (Watters 1999, Ponder and Walker 2003), and displaces aquatic organisms (Walters and Post 2011). Displaced aquatic organisms can be viewed as a bioenergetic loss to aquatic ecosystems as organisms are stranded and die when the irrigation season ends and diversions cease. However, there is a relative paucity of natural history information regarding most freshwater mollusk species (Hershler et al. 2014) despite these organisms' relatively large importance in freshwater food webs (Johnson et al. 2013). Further, our literature review resulted in no studies specifically regarding the bioenergetic loss to riverine ecosystems resulting from entrainment in irrigation canals. For effective conservation and management of these important resources, information is needed regarding the taxonomy, ecology, distribution, and abundance of species (Lysne et al. 2008). For example, gene flow and mortality factors are important population level characteristics (Reece et al. 2014) needed for a complete understanding of conservation and management options. To begin addressing this information gap, we investigated the entrainment-induced mortality of a community of freshwater mollusk in south-western Idaho, USA. Specifically we conducted a systematic survey of a 1km reach of the Phyllis Canal in south-western Idaho to test the hypotheses that H_1) irrigation canals are not a mortality-associated factor for freshwater mollusk populations and, if H_1 is unsupported, H_2) freshwater mollusk species are represented equally in samples of entrained mollusks.

MATERIALS AND METHODS

We conducted a random, systematic sampling design with multiple random starts (Strayer, 1999) in a 1km segment of an irrigation canal on the property of the College of Western Idaho, Ada County, Idaho, USA (Figure 1). Snails were collected between October and December 2013 following the termination of irrigation flows. We first collected a non-random sample to verify that living freshwater mollusks inhabit the canal during the irrigation season. These individuals were preserved in 95% ETOH, measured, and weighed with and without the shell to the nearest 0.001g. We used this information for soft tissue biomass estimations. We divided the canal into ten 100 meter reaches and we superimposed a grid with $1m^2$ cells over each reach. The *RAND* function in Microsoft Excel was used to determine sampling start points within each reach. We determined *a priori* to collect mollusks from nine $1m^2$ cells (hereafter "plots") within each of the ten reaches. Mollusk samples were collected from within a ¼ m^2 quadrat oriented to the southwest corner of each plot. We used hand collections and a timed two minute search to collect as many mollusks as possible from the surface of the canal floor. All specimens were preserved in 95% ETOH and, for the purpose of this study; we assume that all were alive at the time of entrainment. Samples were returned to the laboratory, enumerated and identified to the lowest practical taxonomic level following Burch (1989) for all taxa excepting the Physidae which followed Wethington and Lydeard (2007).

We blotted dry and weighed 167 snails in their shells. We next removed the shell and weighed only the soft tissue mass. This allowed us to calculate biomass of soft tissue as a proportion of total weight. We used *Stagnicola elodes* (Say, 1821) and *Physa sp.* (Draparnaud,

1801) for molluscan community biomass estimates because of their anatomical disparities. *Stagnicola* has a relatively thick shell and less soft tissue and the thin-shelled *Physa* has relatively more soft tissue. Thus we intended our molluscan community biomass estimation to be protected from interspecific variation in shell mass/soft tissue mass ratios. We used the calculated mean ratio of shell mass to soft tissue mass to calculate soft tissue mass for all individuals entrained in the canal and collected in our samples regardless of the presence of soft tissue in accordance with the assumption stated above. Biomass calculations were then extrapolated from our 90 samples to the entire 1km canal segment at the college and then to the entire 78km canal from its departure with the Boise River and terminus in an agricultural field.

Ratios of shell mass to soft tissue mass were analyzed for linearity with Pearson's Correlation Coefficient (r^2). Differences between canal reaches were analyzed with a single-factor ANOVA. Community evenness and diversity were calculated with Chi-Square and Simpsons Diversity and Equitability Index. We assumed a normal distribution of data therefore no transformations were performed.

RESULTS

We collected 483 freshwater mollusks from four families and seven genera (Table 1). The majority of individuals collected belonged to the Lymnaeidae (85%). The remaining specimens belong to the Planorbidae (6%), Spheriidae (5%), or Physidae (3.5%).

A one-way ANOVA was used to test for differences in abundance between taxa across the ten reaches sampled. A significant difference was found ($F = 8.27$, $p < 0.001$) which suggests that at least one group differed from the rest and one or more taxa are disproportionately represented in our collections. *Post hoc* analyses included Simpson's *D* & *E* tests to characterize the molluscan community diversity and equitability. Simpson's index *D* = 0.73 suggests that randomly selecting individual mollusks from our sample area would result in a 73% chance of selecting *Stagnicola* elodes. The probability of randomly selecting two different species from within the Phyllis canal other than *Stagnicola elodes* is described by Simpson's index of Diversity 1-*D* =0.27. This low species diversity can best be visualized using a species importance curve (Figure 2).

Biomass estimations were based off of the nonrandom representative sample, which included 167 individuals from *Stagnicola elodes* (Say, 1821) and *Physa sp.* (Draparnaud, 1801). Using a 90% CI we calculated that the average individual consisted of 58.93831-59.06169% soft tissue and 40.93831-41.06169% shell. We found a strong correlation ($R^2 > 0.95$) between shell mass to soft tissue mass within both *Physa* (Draparnaud, 1801) *and Stagnicola elodes* (Say, 1821)(Figure 3). After extrapolating from the nine plots within each reach to the entire area encompassed by each reach, we estimate that on average each of the ten reaches contained 27.24 g of molluscan soft tissue mass. Continuing this extrapolation for the entire 1 km reach at CWI results in an estimated 272.30 g of molluscan soft tissue mass, finally, in the entire 78 km canal we estimate that 21.24 kg of soft tissue and the energy therein, are lost from the Boise River ecosystem and entrained within the Phyllis Canal.

DISCUSSION

We conducted a systematic random sample of an ephemeral, anthropogenic aquatic system in Nampa, Idaho USA. Our intent was to describe the molluscan community therein, test the hypothesis that irrigation canals represent a population-level mortality factor, and estimate the bioenergetic loss of these primary consumers from the Boise River ecosystem. In addition we endeavored to estimate bioenergetics losses to secondary consumers and higher trophic levels. By understanding the degree to which the molluscan community is impacted by entrainment in irrigation canals will provide natural resources managers with important information for determining conservation priorities (Lysne *et al.* 2008). We found that the molluscan community in the Phyllis Canal is disproportionally represented by *Stagnicola elodes* comprising 85% of specimens collected. Further, we found that over 21 kg of soft tissue were removed from the Boise River and entrained within the canal. The loss of these primary consumers from the Boise River ecosystem to the irrigation canal system might have disadvantageous impacts on the Boise River invertebrate community (Power *et al.* 1996) and also affect the biodiversity of the river system (Vörösmarty *et al.* 2010).

The lack of literature on mollusk entrainment suggests that little research has been done on the effects of mollusk displacement in irrigation systems. However, there is substantial evidence relating to water diversions and hydrological regimes and the implications it has on biota. Kelso and Milburn (1979) demonstrated that up to 25% of the annual production of larval fish in the Great Lakes are impinged or entrained by hydro-electric power plant facilities. Similarly, Grimaldo et al. (2009) demonstrated that large numbers of pelagic and freshwater fishes are entrained in diversion canals in California. According to Vörösmarty *et al.* (2010), 65% of all river discharge and the aquatic habitat it supports are under moderate to high threat from alterations to the natural flow regime. And Power *et al.* (1996) state that unnatural flow regimes resulting from irrigation diversions impact predator-prey interactions and alter bioenergetic pathways in aquatic food webs. The Boise River, like many western North

American streams, is extensively diverted for agricultural purposes (USGS 2014) therefore we may expect that large irrigation diversions such as the Phyllis Canal will entrain fish and invertebrate animals, influence predator-prey interactions, and alter trophic relationships.

Food webs are defined by biomass and energy movement across various trophic levels (Otto *et al.* 2007). Because the Phyllis Canal is one of many diversions from the Boise River we can expect gross bioenergetic losses to be greater. This is disconcerting when considering bottom-up ecological controls because stressors to lower trophic levels can cause major perturbations throughout higher levels (Munawar 2010, Mills *et al.* 2003, Munawar and Munawar 2003, Stewart *et al.* 2009). The loss of primary consumers that we have demonstrated will negatively impact consumers that rely upon these animals for nutrition. We demonstrated that over 21 kg of biomass was lost to the Phyllis Canal. Azevedo *et al.* (2005) found a 55% transfer rate in rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792) and a 57% transfer in Atlantic salmon, *Salmo salar* (Linnaeus, 1758). Assuming that all 21 kg of mollusks are consumed by some member of the Salmonidae, this would result in over 11 kg of trout biomass lost from the Boise River ecosystem On average bald eagles, *Haliaeetus leucocephalus* (Linnaeus, 1766), that overwinter on the Nooksack River in northwestern Washington consume 489 g of salmon per day (Stalmaster and Gessaman 1984). Similar research on the Boise River in Idaho found that fish comprised an important component of wintering bald eagles diet (Spahr, 1990). Finally, the abundance of adequate food resources is known to influence bald eagle reproductive success (Stalmaster, 1987). Our logic-path is but one of many plausible scenarios regarding alterations to bioenergetic pathways and trophic dynamics.

Our systematic study demonstrated that entrainment of freshwater mollusks in the Phyllis Canal is a mortality factor for populations of mollusks in the Boise River ecosystem (H_1). Fortunately none of the ten species entrained are of critical conservation concern (Table 1). In addition, we show that individuals of the gastropod genus *Stagnicola* (Jeffreys, 1830) are disproportionately represented in the Phyllis Canal, thus we reject our second hypothesis (H_2). The reason for this lack of homogeneity is unclear and requires further study. Further, a complete understanding of freshwater mollusk community structure, and the role of these organisms in Boise River ecosystem trophic dynamics, is required to effectively prioritize conservation efforts and achieve conservation goals. Because our study was conducted in the winter, both live and moribund individuals were collected. However, because it cannot be discerned, we assumed that all individuals were entrained live and this may have biased our analysis toward overestimating biomass losses. The biodiversity and ecology of the Boise River ecosystem should be of concern to natural resource managers and the public. While we are not advocating any management actions, understanding ecological relationships is necessary antecedent to effective prioritization of management options.

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Figure 1: Map showing Phyllis Canal and Boise River in southwestern Idaho, USA.

Family	Genus	Species	Authority	Number Sampled	G Rank
Gastropods					
Lymnaeidae	*Stagnicola*	*elodes sp.*	Say, 1821	412	G5
Physidae	*Physa*	sp.	Draparnaud, 1801	17	NA
Planorbidae	*Gyraulus*	circumstriatus	Tryon, 1866	24	G5
Planorbidae	*Planorbella*	trivolvis	Say, 1817	3	G5T5
Planorbidae	*Planorbella*	subcrenata	Carpenter, 1857	1	G5
Bivalves					
Sphaeriidae	*Pisidium*	fallax	Sterki, 1896	2	G5
Sphaeriidae	*Pisidium*	sp.	Pfeiffer, 1821	19	G5
Sphaeriidae	*Pisidium*	conventus	Clessin, 1817	1	G5
Sphaeriidae	*Sphaerium*	simile	Say, 1817	2	G5
Sphaeriidae	*Musculium*	lacustre	Müller, 1774	2	G5

Table 1: Mollusks collected in 2013 in the Phyllis Canal, Idaho, USA (n = 483). G-rankings from NatureServe (2014).

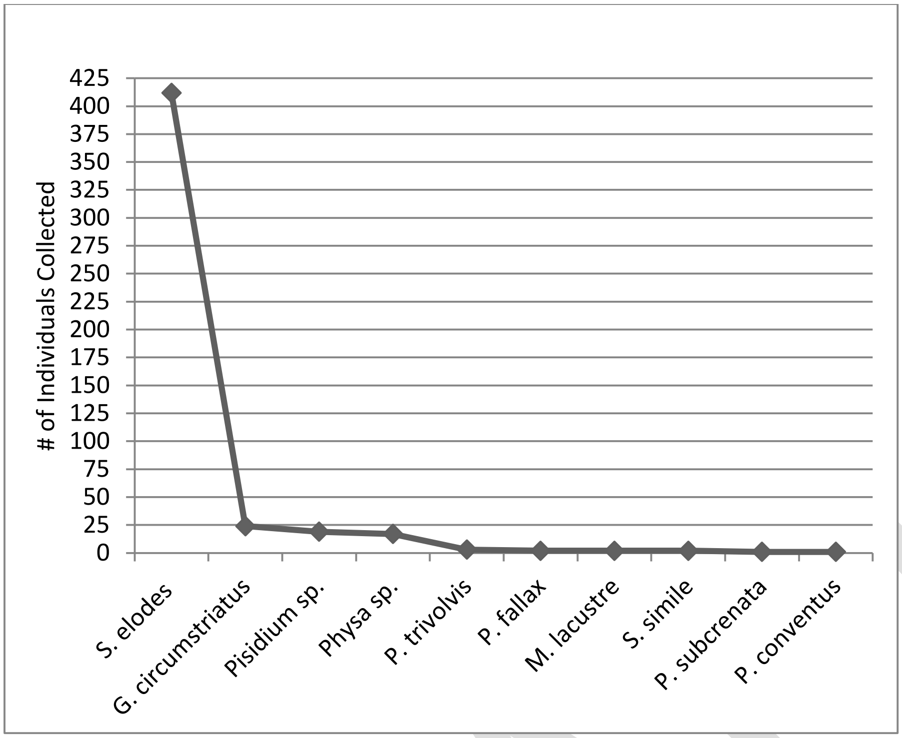

Figure 2 Importance curve for mollusks collected during 2013 in the Phyllis Canal, Idaho, USA (n = 483) graphically depicts our low biodiversity.

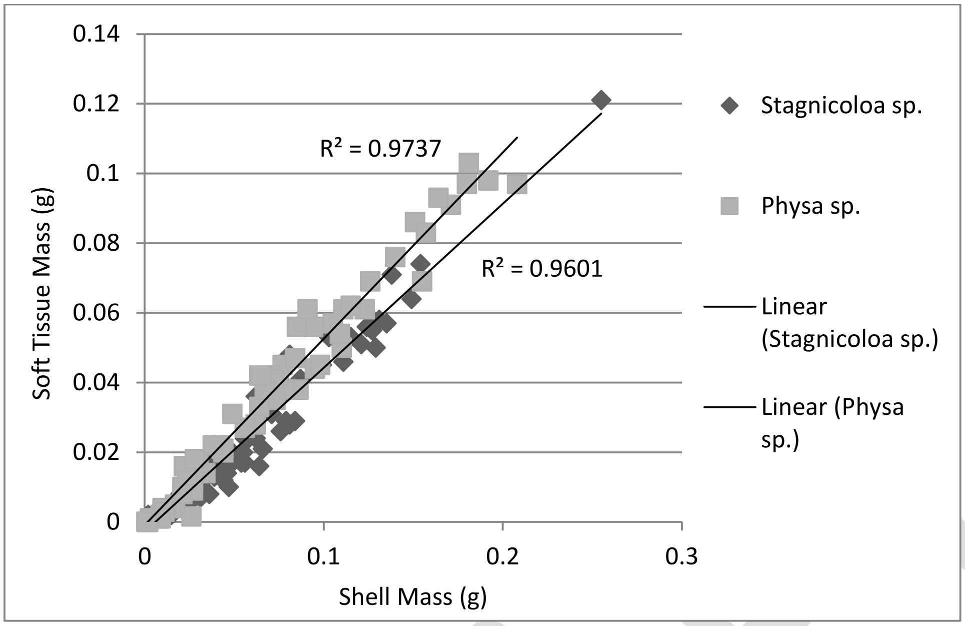

Figure 3 Relationship between shell mass and soft tissue mass for two species used to estimate total biomass in this study (n = 167).