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Survival and Growth Rate of Translocated Freshwater Mussels *Lampsilis fasciola* and *Medionidus conradicus*

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To the Graduate Council:

I am submitting herewith a thesis written by Laura L. Pullum entitled "Survival and Growth Rate of Translocated Freshwater Mussels *Lampsilis fasciola* and *Medionidus conradicus*." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

Michael McKinney, Major Professor

We have read this thesis and recommend its acceptance:

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Survival and Growth Rate of Translocated Freshwater Mussels *Lampsilis fasciola* and *Medionidus conradicus*

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Master of Science
Degree
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Laura L. Pullum
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ABSTRACT

Freshwater mussels (Family Unionidae and Margaritiferidae) are a widely threatened group of bivalve molluscs, particularly in the Southeastern United States. Translocation of freshwater mussels is an increasingly common conservation method. However, there are relatively few studies that quantitatively investigate the factors influencing translocation success or failure. In October 2013, hundreds of *Medionidus conradicus* and *Lampsilis fasciola* were translocated to the Pigeon and Nolichucky Rivers in Tennessee, with an interim partial survey (June 2014) and a full survey (October 2014). In this study, I analyze this field-collected data to determine the mechanism(s) that currently influence the outcomes of Tennessee mussel translocation.

My recommendations for future surveys include open and timely data sharing between investigators and the scientific community at large. Given these data and associated collection methods, a better understanding of freshwater mussel communities and restoration success factors can be identified at lower future costs and facilitate longer-term research. My research recommendations include more frequent, complete surveys, and quantitative analyses at the mussel and community levels.

The results of this study have implications for conservation translocation efforts. My results indicate that both *L. fasciola* and *M. conradicus* can be successfully translocated to the Pigeon River, if 1) they are translocated to the Pigeon where it has less boulder, cobble and exposed bedrock in favor of more coarse and fine gravel and sand; 2) it had lower peak and average water discharge rates, 3) if some translocations occurred in the spring-early summer, and 4) if the translocated mussels are initially housed in cages or silos. The non-housed mussels were not recovered, primarily due to high water volumes and velocities soon after the beginning of the study. The housed mussels were protected. There is no overall predictability of the water discharge timing and size of the Waterville Hydroelectric Power plant's dam. A management recommendation is for incremental releases and notification to conservation authorities. Due to significant mortality in the first 8 months of this study, some studies should start in the spring-early summer rather than in October to help translocated mussels survive their first over-winter by having some growth and habitat acclimation underway.

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CHAPTER 1
INTRODUCTION

1.1 The Rise and Fall of Freshwater Mussel Fauna

Freshwater mussels are an important indicator of ecosystem health and biodiversity (Neves et al. 1997; Haag & Rypel, 2011; Hubbs, 2014). North America's freshwater mussels are bivalve mollusks of the order Unionida, families Unionidae and Margaritiferidae. They function to filter water, their biodeposition increases food availability for other organisms and their burrowing releases nutrients from, and increases the oxygen content of, the sediment. Freshwater mussels play an important role in nutrient cycling by reducing the amount of suspended organic matter in the water column, which otherwise could lead to eutrophication. In addition, they are a food source for fish, aquatic and near-shore mammals, and shore birds. (Haag, 2012) North America has the highest freshwater mussel diversity, with estimates of around 300 species (Williams, et al. 1993; Graf & Cummings, 2007; Vaughn, et al. 2004), with the Tennessee River Basin historically home to 102 species (Parmalee & Bogan, 1998).

Populations of some freshwater mussels have shown severe decline due to a series of human engineering projects that resulted in habitat loss and degradation of river and lake ecosystems (Graf 2007; Lyons et al. 2007). Thirty-five species of freshwater mussels have become extinct in the past 100 years (Neves et al. 1997). Environmental factors that occur at large spatial scales have influenced the decline, extirpation and extinction of freshwater mussels in North America, including systematic habitat destruction by dams and other river modification projects, pollution (e.g., chemical spills, mine and agriculture run off), and flow instability. (Goudreau et al. 1993; Diamond & Serveiss, 2001; Havlik & Marking, 1987; Aldridge et al. 1987; Neves et al. 1997).

Efforts have been made to correct habitat destruction at large spatial scales (e.g., within the Tennessee River Basin), so that the sites may be viable recruitment grounds for mussel population enhancement. For example, the Tennessee Valley Authority (TVA) has implemented several methods to improve the dissolved oxygen concentrations in the benthos of tailwater sections of rivers below dams. These methods include use of aerating turbines, surface-water pumps, oxygen injection systems and aerating weirs to eliminate hypoxia by reaching dissolved oxygen concentration targets (daily minimum of 5.0 mg/L) necessary for benthic invertebrate and fish life (Brookshier et al. 1999). These large-scale restoration efforts are necessary, but will likely be insufficient for adequate recovery of historic mussel populations. Reintroduction efforts for mussels following habitat restoration have largely been unsuccessful. To date, however, few multi-factor studies have been conducted to understand the mechanism(s) influencing the success of Tennessee freshwater mussel translocation efforts.

1.2 Habitat Factors that Influence Freshwater Mussel Mortality and Growth

Many factors influence the growth, lifespan and abundance of freshwater mussels, including the environmental factors – habitat destruction, pollution and flow instability. The freshwater mussel life cycle and habitat present additional factors. For instance, the mussel's life cycle (Figure 1-1) is one of the most complex of any group (US FWS 2006). The male mussel releases sperm into the water. The water and sperm are siphoned by nearby female mussel and enter the female's gills, where eggs are fertilized and develop there for several weeks. The next stage of the lifecycle is the emergence of microscopic mussel larvae, called glochidia. The female releases the glochidia (via various taxa-specific methods) and they attach to a host to develop.

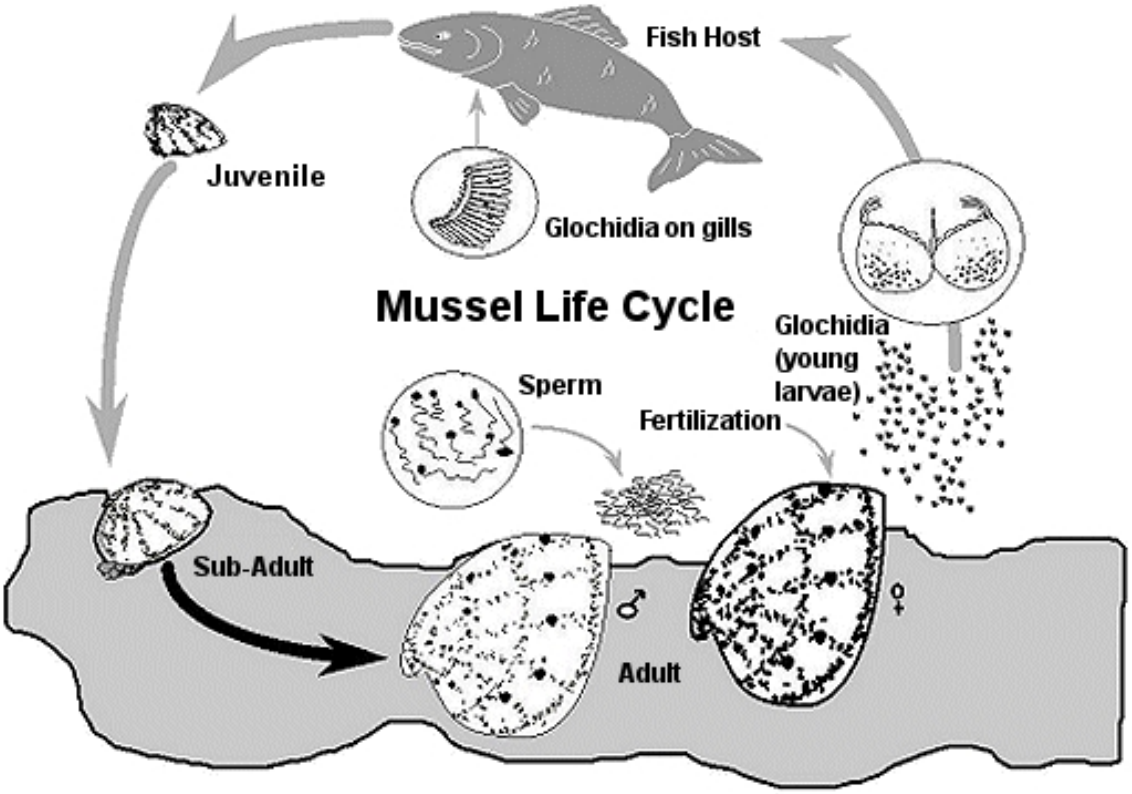

Figure 1-1. Freshwater Mussel Life Cycle [Source: Freshwater Mussels of Iowa, 2002, life cycle diagram: Mississippi River, Lower St. Croix Team, Wisconsin Department of Natural Resources]

Most freshwater mussels prefer specific hosts and the mussels studied herein use fish as hosts (as do most freshwater mussels). Already we see that water flow and host availability are factors in mussel survival and recruitment. The glochidia attach to the host's gill tissue, which provides food and shelter for glochidia development. The larval glochidium develops into a juvenile mussel within several weeks, and then drops off the host to the substrate. The juvenile continues to develop to a sub-adult stage, and then to an adult. A mussel is considered mature or adult upon reproductive maturity. In this latter part of the life cycle, we note additional factors affecting the survival and recruitment of mussels including host fish availability, the ability to attract hosts, and the availability of suitable substrate. Parasitic life cycle and selective dependence on hosts for dispersal to suitable habitats are complicating factors for mussel conservation (Neves et al., 1997; Strayer et al., 2004; Zipper, et al. 2014).

Predators of adult freshwater mussels include: *Lutra canadensis* (Otter), *Ondatra zibethicus* (Muskrat), *Procyon lotor* (Raccoon), *Mephitidae* (Skunk), *Laridae* (Gull) and *Scolopacidae* (shore birds). Juveniles are eaten by *Platyhelminthes* (Flatworm), *Hirudidae* (Leech), and *Cambaridae* (Crayfish) (Strayer & Smith, 1996), and freshwater fish including *Cyprinidae* (Carp), *Acipenseridae* (Sturgeon), *Ictaluridae* (Catfish), and *Centrarchidae* (Sunfish) (Haag, 2012).

Mortality rates and survivorship curves are unknown for most mussel species, presenting a major challenge in distinguishing between natural and human influenced population fluctuations (Jones & Neves, 2011). However, the few existing studies indicate significant variability in mortality, longevity and growth (Jokela & Mutikainen, 1995; Villella et al., 2004, Haag & Rypel, 2011). In general, freshwater mussels produce a large number of glochidia from which a relatively few survive to maturity. Mussels are typically characterized as having low mortality and long life spans (Hart et al., 2001).

Habitat factors such as dissolved oxygen (Strayer & Smith, 1996), temperature (Bogan, 2001; Rodland et al., 2009), pH, chemical and metal concentrations, and sedimentation disturbances (Ellis, 1936) have been suggested (Strayer et al., 2004) as additional mussel survival factors. However, subsequent studies showed that some environmental factors had almost no explanatory power (e.g., sediment grain size and current velocity [Strayer & Ralley, 1993]). Availability of food and fish hosts for mussel glochidia attachment is fundamental, because effective recruitment and dispersal are critical to the continuity of a population. In addition, non-native species such as the zebra mussel, *Dreissena polymorpha*, reduce food and habitat available for native mussels, and increased parasite densities (e.g., trematodes (Gangloff et al., 2008)) can reach a level that reduces mussel reproductive output.

1.3 Tennessee Efforts to Restore Freshwater Mussels

Relocation of freshwater mussels from one location containing robust mussel population(s) to another, presumably better, location has been used as a conservation strategy for freshwater mussels for over 35 years (Cope and Waller, 1995). In an effort to avoid confusion caused by all of the terms defining relocation, and to harmonize the freshwater mussel literature, Cope (2003) proposed the term *relocation* to refer to any intentional movement by humans of an individual or population from one location to another. However, more recently, the World Conservation Union (IUCN, 2013) defined the following:

- ***Translocation*** - the human-mediated movement of living organisms from one area, with release in another.
- ***Conservation translocation*** - the deliberate movement of organisms from one site for release in another. It must be intended to yield a measurable conservation benefit at the levels of a population, species or ecosystem, and not only provide benefit to translocated individuals.

Further, conservation translocations consist of a) reinforcement and reintroduction *within* a species' indigenous range (includes augmentation), and b) conservation introductions, comprising assisted colonization and ecological replacement, *outside* indigenous range (IUCN, 2012). All of the efforts reported herein are conservation translocations, and will be referred to as translocations. When reporting results from other authors, I use their terminology or the more general term, relocation.

The Virginia Department of Game and Inland Fisheries (VDGIF) Aquatic Wildlife Conservation Center (AWCC) cultivates freshwater mussels for augmentation purposes. Conservation of freshwater mussels in the Tennessee River Basin has used both approaches.

Cope and Waller (1995) reviewed 33 papers and reports on freshwater mussel relocation efforts. They found that over 90,000 mussels had been relocated over the 37 projects discussed in the 33 documents, with a mean mortality rate of 49%. Roughly a third of the documents reported mortality rates of over 70%. Half of the relocations occurred in the Southeastern US during summer months (July through September). The reasons for the high mortality remain unclear because of lack of long-term monitoring and inadequate habitat characterization of the relocation sites.

A major obstacle to mussel recovery in Tennessee is the fragmentation of riverine habitats by dams and impounded waters (TWRA, 2015). In Tennessee, habitat conditions in some rivers that once supported a diverse mussel fauna have been restored sufficiently to again support mussels. This is thought to be the case for the Pigeon River site included in this study. The Tennessee Valley Authority (TVA) began a Reservoir Release Improvements program in the 1990s at all their tributary dams to provide constant minimum water flows and improve water quality (e.g., increased oxygen content).

The Tennessee Wildlife Resources Agency (TWRA) is the regulatory body primarily responsible for conservation and management of Tennessee's mussels and other biological resources (TWRA, 2015). Cooperative efforts between TWRA, other agencies and the public have resulted in the development of publications to help guide recovery and conservation efforts of mussels. These include

- Tennessee State Wildlife Action Plan (TWRA, 2005),
- Plan for the Controlled Propagation, Augmentation, and Reintroduction of Freshwater Mollusks of the Cumberlandian Region (Cumberlandian Region Mollusk Restoration Committee, CRMRC 2010), and
- Tennessee Freshwater Mollusk Strategic Plan (Tennessee Chapter of The Nature Conservancy, 2013).

TWRA's aquatic species restoration actions follow the Myers' Rule which states that "listed endangered/threatened species can be stocked into Tennessee waters/locations where other listed species are extant for these actions do not change the regulatory status of the site" (TWRA, 2015). Under the direction of Don Hubbs, the TWRA Mussel Restoration Project has translocated mussels in Tennessee since 2004. Table 1-1 (developed from data provided in (TWRA, 2015)) details and summarizes those efforts. Using 6 distinct source rivers and 14 distinct destination or recipient rivers, the TWRA has translocated over 45,000 mussels since 2004. In 2014, over 6,700 mussels were translocated. Of those, over 75% were federally endangered species.

Communication from the Pigeon River Relocation Project coordinator (J. Coombs, UT) states that freshwater mussels were released in the Pigeon River (at PRM 8.4, near the mouth of English Creek) in 2000 (number and species not available). Additional translocations occurred in August 2010 (50 *L. fasciola* by the North Carolina Wildlife Resources Commission (NCWRC) above Canton mill) and 2011 (58 *L. fasciola* by NCWRC below Canton mill and upstream of the confluence with Richland Creek).

Table 1-1. TWRA Freshwater Mussel Translocations

Source	Recipient	Species	Year											Total
			2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
VDGIF/ Tennessee River @ Diamond Island stock	Clinch @ Kyles Ford in downstream end of pool and head of riffle	*Lampsilis abrupta*									300	100	113	513
		River Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**300**	**100**	**113**	**513**
Clinch @ Kyles Ford includes Clinch stock VDGIF progeny	Duck @ Milltown	*Ptychobranchus subtentum*			211	850	239		757	693	710	602	900	4,962
		Epioblasma brevidens				108	76		210	458	380	599	518	2,349
		Cumberlandia monodonta				9	1							10
		Epioblasma triquetra								330	150	27		507
		L. abrupta										298		298
		Cyprogenia stegaria										54	45	99

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	Recipient	Species	Year											Total
			2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
VDGIF/ Tennessee River @ Diamond Island stock	Duck @ Littlelot Hwy 230	*L. abrupta*										121		121
Saline River Arkansas brood stock/ Kansas City Zoo progeny	Duck @ Littlelot Hwy 230	*Quadrula fragosa*										103		103
Clinch @ Kyles Ford, Frost Ford, & Wallen Bend	Duck @ Slick Shoals and Duck @ Shelbyville Dam	*P. subtentum*	200	115	142									457
Estill Fork of Paint Rock	Duck @ Venable Spring	*Toxolasma cylindrellus*	200	115	88									403
		River Total	**400**	**230**	**441**	**967**	**316**	**0**	**967**	**1481**	**1240**	**1804**	**1463**	**9,309**

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	**Recipient**	**Species**	**Year**											**Total**
			2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
AABC/ Paint Rock stock	Elk below Harms Mill and Elk @ Winding Stair Bluff	*Lampsilis virescens*							430	532	500			1,462
VDGIF/ Tennessee River @ Diamond Island stock	Elk below Harms Mill and Elk @ Winding Stair Bluff	*L. abrupta*										200		200
AABC/ Paint Rock stock	Elk @ Winding Stair Bluff	*L. virescens*									3,000			3,000
		River Total	**0**	**0**	**0**	**0**	**0**	**0**	**430**	**532**	**3,500**	**200**	**0**	**4,662**
Clinch @ Kyles Ford includes Clinch stock VDGIF progeny	Emory @ Hwy 299 Bridge, Oakdale	*Epioblasma capsaeformis*									525	738	149	1,412
		Medionidus conradicus									200	200	500	900
		River Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**725**	**938**	**649**	**2,312**

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	Recipient	Species	Year											Total
			2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Clinch @ Kyles Ford includes Clinch stock VDGIF progeny	Hiwassee @ McClary Island	*E. capsaeformis*									2,269		500	2,769
		M. conradicus									800			800
		River Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3,069**	**0**	**500**	**3,569**
Duck @ Milltown	Noli-chucky @ upper Hale Bridge	*Lemiox rimosus*				212	176							388
Clinch @ Kyles Ford, Frost Ford, & Wallen Bend		*M. conradicus*	201											201
		Actinonaias pectorosa	97											97
		E. brevidens				44								44
		E. capsaeformis				130	240							370
		P. subtentum	164	120	171	238	200							893
		Site Total	**462**	**120**	**171**	**624**	**616**	**0**	**0**	**0**	**0**	**0**	**0**	**1,993**

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	**Recipient**	**Species**	**Year**											**Total**
			2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
Clinch @ Kyles Ford includes Clinch stock VDGIF progeny	Noli-chucky @ TWRA canoe launch	*E. brevidens*						83	200	346	380	400	485	1,894
		E. capsaeformis						308	799	2,128	1,895	1,807	700	7,637
		P. subtentum						637	400	700	765	675	685	3,862
		M. conradicus							506	826	500	549	500	2,881
Duck @ Milltown		*L. rimosus*							380	562	390	330	278	1,940
VDGIF/ Tennessee River @ Diamond Island stock		*L. abrupta*											130	130
		Site Total	**0**	**0**	**0**	**0**	**0**	**1028**	**2285**	**4,562**	**3,930**	**3761**	**2778**	**18344**
		River Total	**462**	**120**	**171**	**624**	**616**	**1028**	**2285**	**4,562**	**3,930**	**3761**	**2778**	**20337**
Duck @ Milltown	Pigeon @ Wilton Springs	*Cyclonaians tuberculata*								217				217
		Quadrula pustulosa								59				59
		Elliptio dilitata								47				47

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	**Recipient**	**Species**	**Year**											**Total**
			2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
Tennessee River @ Diamond Island	Pigeon @ Wilton Springs	*Q. pustulosa*								132				132
Clinch @ Kyles Ford		*Actinonaias ligamentina*										372	59	431
		A. pectorosa										4	199	203
		C. tuberculata										88		88
		E. dilitata										108	36	144
		Lampsilis ovata										5		5
		Ptycho-branchus fasciolaris										76	51	127
		Villosa iris								100		122		222
		L. fasciola								100		237		337
		Q. pustulosa										17		17
		M. conradicus								100		284	217	601
		Site Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**755**	**0**	**1313**	**562**	**2,630**

Table 1-1. TWRA Freshwater Mussel Translocations. Continued

Source	Recipient	Species	Year											Total
			2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Tennessee River @ Diamond Island	Pigeon @ Denton	*C. tuberculata*									909			909
		Q. pustulosa									911			911
VDGIF Propogat-ed/ Clinch stock		*L. ovata*									200			200
Clinch @ Kyles Ford		*M. conradicus*									300			300
Site Total			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2,320**	**0**	**0**	**2,320**
River Total			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**755**	**2,320**	**1313**	**562**	**4,950**
Year Total			**862**	**350**	**612**	**1591**	**932**	**1028**	**3682**	**7,330**	**15084**	**8116**	**6065**	**45652**

The TWRA conducted mussel translocation in the Nolichucky River since 2004 and in the Pigeon River since 2011. The study reported herein was based on translocations and data collected as part of the TWRA efforts during the October 2013 – September 2014 timeframe.

1.4 Research Study

The research presented herein examines the success of conservation efforts at two sites, one of which has been recently deemed sufficiently restored for mussel reintroduction. Both translocation and augmentation conservation strategies are examined via tagging and surveying two mussel species over approximately one year. Quantitative growth and survival data were collected, and data on river conditions were obtained by testing water quality and from available USGS water quality sites. This research quantitatively examines the rivers, mussel species, and housing factors to determine their impact on the success of the translocation efforts of *Lampsilis fasciola* and *Medionidus conradicus* in the Pigeon River and the Nolichucky River.

CHAPTER 2
SITE AND SPECIES BACKGROUND

In October 2013, mussels were translocated from the Clinch River at Kyles Ford (in Tennessee) to the Pigeon River at the confluence with Cosby Creek and in the Nolichucky River, Tennessee. Additional mussels were stocked from the Virginia Department of Game and Inland Fisheries' (VDGIF) Aquatic Wildlife Conservation Center (AWCC) to the same locations. This chapter provides background on each site and for the species translocated to those sites. The following chapter will describe the materials and methods used in the translocation and the subsequent surveys and analyses.

2.1 Sites

Figure 2-1 provides a map of the study site locations. These include the Clinch River at Kyle's Ford (36°25'30", 83°23'54") NADV27, the Pigeon River at Cosby Creek (35°57'38", 83°10'28"), and the Nolichucky River at the TWRA Canoe Access (36°10'35", 82°27'27"). The University of Tennessee at Knoxville (UTK) is included for reference. Table 2-1 provides the location of each site, and its altitude and a brief description of its substrate.

Table 2-1. Site location, altitude and substrate

Location Name	Lat, Lon (NADV27)	USGS Site	Altitude (meters above NGVD 29)	Drainage Area (sq. kilometers)	Substrate
Clinch River	36°25'30", 83°23'54"	03528000	323.3	3817.6	Cobbles and sand
Pigeon River	35°57'38", 83°10'28"	03461500	316.6	1724.9	Boulders, cobbles, fine sediments
Nolichucky River	36°10'35", 82°27'27"	03465500	463.1	2084.9	Cobbles, sand, fine sediments

Figure 2-1. Study Site Locations: Clinch River at Kyle's Ford, Pigeon River at Cosby Creek, Nolichucky River at the TWRA Canoe Launch. The University of Tennessee at Knoxville is included for reference. Map courtesy of Google®.

2.1.1 Clinch River at Kyles Ford

Above the Norris Reservoir is an unimpounded portion of the Clinch River located in northeast Tennessee (Figure 2-1). It supports diverse healthy populations of native freshwater mussels. Fifty-six mussel species have been reported in this region (Stansbery, 1973; Jones et al., 2014), with 10 expected to be extinct or extirpated in the next 50-100 years. Twenty-four of the extant mussel species are either federally endangered or proposed for federal listing (Hubbs, 2014). Thus, the Clinch River has been designated a priority conservation area by the US Fish and Wildlife Service (US FWS, 2012). Although several of the Clinch mussel populations are in decline, this site remains one of the highest in terms of freshwater biodiversity (Neves et al. 1997; Parmalee & Bogan, 1998). In fact, this site serves as a source for some of the translocation efforts underway because of its consistent abundance of some species.

In addition, the glochidia of source *L. fasciola* from the Clinch were collected as brood stock for propagation at the AWCC in VA. Harvesting begins with removing a few glochidia from the female and testing their viability. Viable glochidia will snap close when placed in the proximity (e.g., in a small dish) of a few grains of salt. The salt is a proxy for the chloride in fish blood, so the closing reaction indicates the glochidia are ready to infest a host fish. Viable glochidia are removed from the female, placed in an aerated container with a known host fish, and the infestation begins. When infestation is complete, the fish and glochidia are transferred to tanks and closely observed for 2 weeks for the appearance of juvenile mussels. (VDGIF, 2014)

2.1.2 Nolichucky River

The Nolichucky River in Tennessee at Evans Island (the TWRA Canoe Access) is the second translocation site (Figure 2-1). In 1913, the Nolichucky Dam was built, creating Davy Crocket Lake. In 1972, the dam was taken out of service and the reservoir was converted into a wildlife management area (Hubbs, 2014). A 1980 survey (Ahlstedt, 1986) identified 21 species of freshwater mussels in a 56 km stretch of the river, with only 2 of the species exhibiting recent recruitment (Hubbs 2014). High concentrations of sand from past mica and feldspar mining in the watershed caused severe impacts to aquatic life downstream (TVA 1994). Since the 1980 survey, water quality conditions have improved so that reintroduction of freshwater mussels can be considered.

2.1.3 Pigeon River at Cosby Creek

The Pigeon River of North Carolina and Tennessee has a long history of habitat degradation from a large dam, urban and farm runoff and high levels of toxic effluents from a paper mill in Canton, North Carolina, which was constructed in 1908. The combined impacts of these disturbances caused the extirpation of all native mussel, and many fish, species downstream from Canton, North Carolina to the confluence with the river in Tennessee, a 101 km section of stream (Bartlett, 1995). Over the last 20 years, the paper mill has modernized and greatly reduced water use and waste production, thereby improving water quality in the Pigeon River (NCDENR, 2008). Consequently many host (fish) species have returned to the river, providing support for native mussel populations. Because of these improvements and the identification of extirpated mussel species from previous archeological studies and observations by experts, the TWRA decided to attempt mussel restoration via translocation (Hubbs, 2014) in the Pigeon River at the Cosby and Denton sites.

2.1.4 Brood Stock from the VDGIF AWCC

The VDGIF AWCC, located near Marion, VA, was established in 1998 by the Virginia Department of Game and Inland Fisheries to actively recover Virginia's freshwater mussels. The AWCC cultivates freshwater mussels and provided *L. fasciola* subadult mussels for the TWRA translocation efforts surveyed and analyzed in this research.

When juvenile mussels release from the host fish, they are collected via an outflow filter of the water recirculation system. Separate systems are used for large fish such as Largemouth Bass (*Micropterus salmoides*), and smaller fish such as Darters (*Percidae*) (AWCC 2014). Collected juvenile mussels are counted and measured, and placed in a rearing system allowing the mussels to grow large enough for translocation or augmentation and increasing their chances of survival in the wild. The rearing systems use filtered river water to eliminate predators that might consume small juveniles, and keep water chemistry as close to natural as possible. Through this system, the AWCC staff can control the water temperature and food content. (AWCC 2014)

2.2 Species

Translocated species in this study include *Lampsilis fasciola* and *Medionidus conradicus*. Information for the species is provided below.

2.2.1 *Lampsilis fasciola*

The Wavyrayed Lampmussel, *L. fasciola* (Rafinesque, 1820), is a freshwater mussel whose range in the United States and Canadian provinces is the Eastern US and Quebec, Canada (Figure 2-2). In Tennessee, its conservation status is “apparently secure” (NatureServe, 2014a). The short-term trend for *L. fasciola* is “relatively stable to decline of 30%”, where most of the decline is seen in Canada, Illinois, New York and Mississippi (NatureServe, 2014a). *Lampsilis fasciola* (Figure 2-3) is a small to medium-river species, and is found at 1 meter or less depth. The preferred substrate of *L. fasciola* appears to be a mixture of sand, cobble and gravel (Gordon and Layzer, 1989). It occurs in small creeks and medium-sized rivers in East and Middle Tennessee, and in the mainstem Cumberland and Tennessee River reservoirs (Parmalee & Bogan, 1998). It is extirpated from several Tennessee

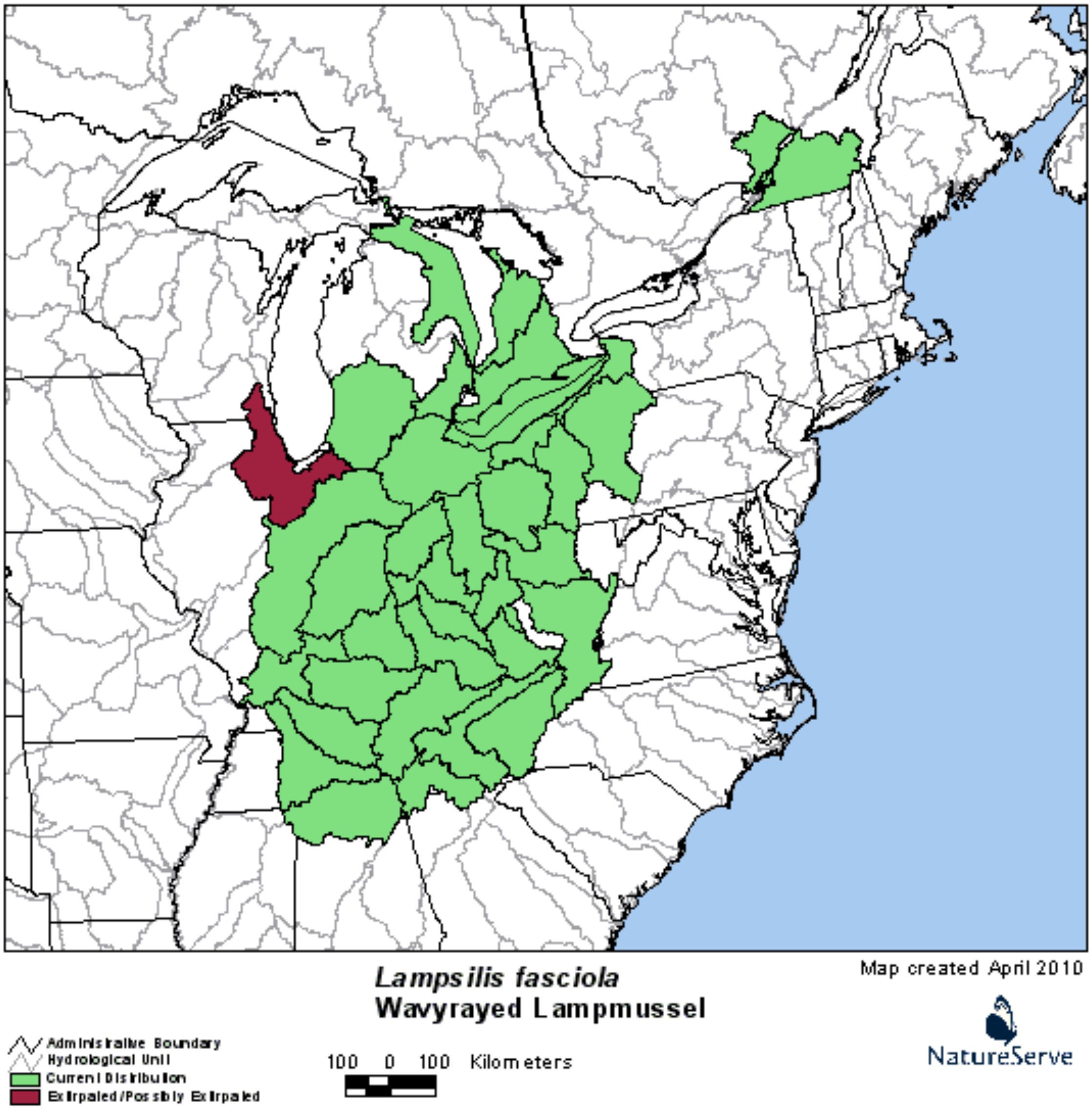

Figure 2-2. *L. fasciola* US range ((NatureServe, 2014a), last accessed 05/12/2015)

Figure 2-3. ***Lampsilis fasciola*** **(Encyclopedia of Life, http://eol.org/pages/449571/overview, last accessed 4/3/2015)**

rivers, including the Watagua, Emory, French Broad, Sequatchie, Buffalo, and others (Parmalee & Bogan, 1998). The shape of the shell is elliptical and its thickness ranges from thin to thick/dense. The length of *L. fasciola* at maturity can reach 90-100 mm (Parmalee & Bogan, 1998). Haag and Rypel (2011) identify Lampsilini as short-lived though they found a great range of longevity (4-50 years). Scott (1994) states a maximum age of 32 years for males and 24 years for female *L. fasciola* observed in the Clinch River in Virginia. The host fish for *L. fasciola* are listed in Table 2-2.

2.2.2 *Medionidus conradicus*

M. conradicus (Lea, 1834), or Cumberland Moccasinshell, is a freshwater mussel whose range is the Southeastern US (Figure 2-4), endemic to the Tennessee and Cumberland River drainages. In Tennessee, its status is "Vulnerable" (NatureServe, 2014b). Its short term trend is a decline of 10-30%, with a long term trend of 30-50% decline (NatureServe, 2014b). This species is found in small- to medium-sized streams such as the Clinch, Powell, Holston, Emory, Watagua, and other rivers (Tennessee). The shell of *M. conradicus* is elongate and elliptical, and relatively thin (though it thickens with age) (Parmalee & Bogan, 1998). This is a small species (Figure 2-5), typically under 60 mm long.

It is found in moderate-strong currents at depths of less than 1 meter. *Medionidus conradicus* habitat is sand and gravel substrate, though it is also found in bedrock cracks and under flat rocks (Parmalee & Bogan, 1998). Glochidia are present on females in mid-September and are discharged in mid-late May (Ortmann, 1921). There are few details on the life history and age of *M. conradicus*, however, Scott (1994) states a maximum age of 24 years for specimens in the Clinch River in Virginia. The host fish for *M. conradicus* are listed in Table 2-2.

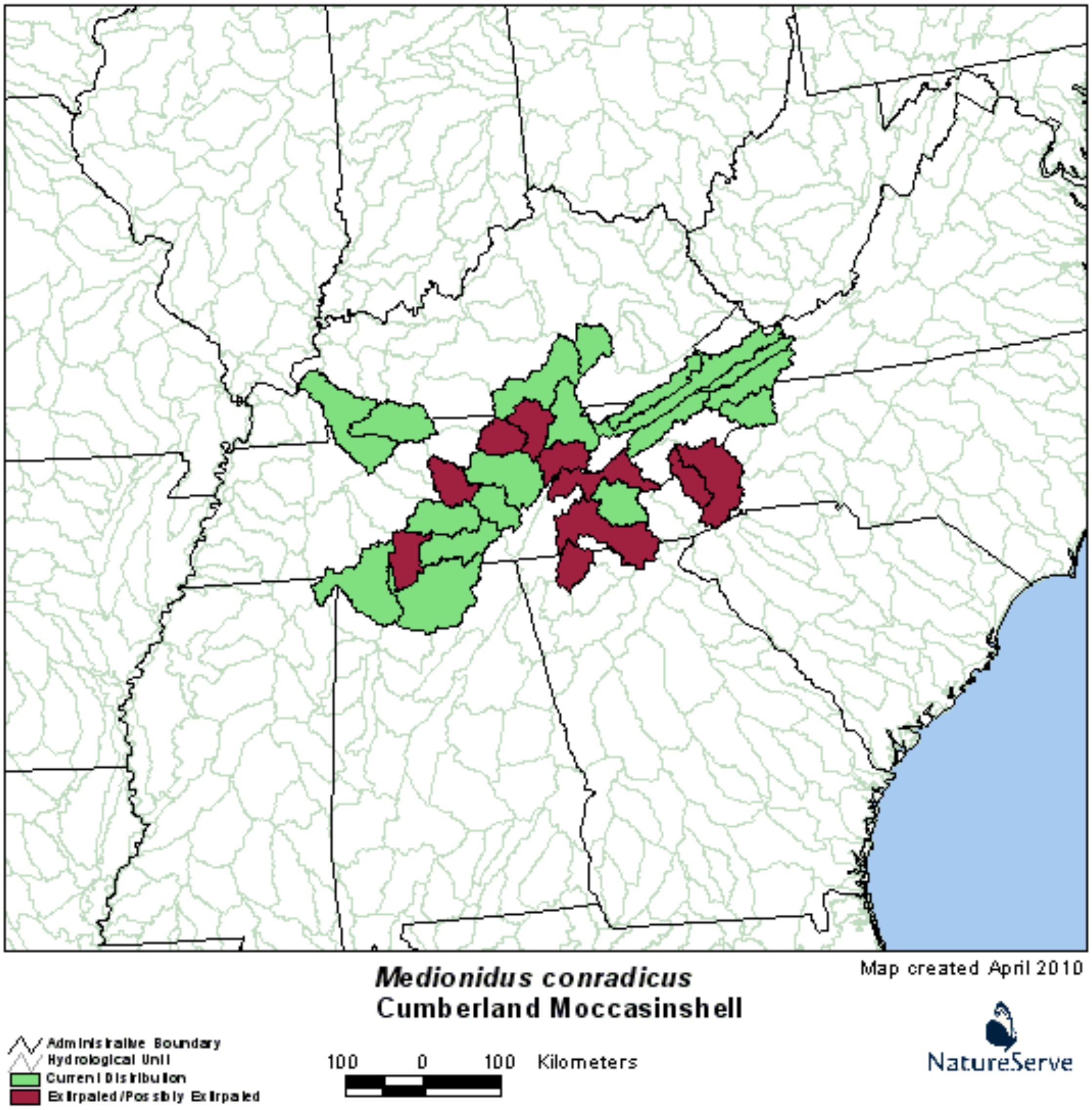

Figure 2-4. ***M. conradicus*** **US range ((NatureServe, 2014b), last accessed 05/12/2015)**

Figure 2-5. ***Medionidus conradicus*** **(Encyclopedia of Life, http://eol.org/pages/449332/overview, accessed 4/3/2015)**

Table 2-2. Host Fish for Introduced Mussels

Freshwater Mussel	**Host Fish (natural)**
L. fasciola	*Smallmouth Bass (*Micropterus dolomieu*) (Zale and Neves, 1982) Black Bass (*Micropterus spp*) (Jones & Neves, 2011) Longear Sunfish (*Lepomis megalotis*) (Watters et al., 2009)
M. conradicus	*Fantail Darter (*Etheostoma flabellare*), *Redline Darter (*Nothonotus rufilineatum*) (Zale & Neves, 1982) Rainbow Darter (*Etheostoma caeruleum*), Striped Darter (*Etheostoma virgatum*) (Luo & Layzer, 1993)

*Primary Host

CHAPTER 3

MATERIALS AND METHODS

3.1 Overview

This study evaluates the results of translocation of *L. fasciola* and *M. conradicus*, to two river sites. Mussel growth and survival are used as proxies for the near term success of the translocation efforts. Additional analyses are conducted to identify factors most influencing growth and survival. My null hypothesis is that there is no difference in growth or survival regardless of mussel species, destination river, or housing type (cage or silo). I expect, however, that the river and species influence both the growth and survival of translocated freshwater mussels.

All mussels were attached with a colored tag (white) with a unique numeric identifier. This allowed us to collect data on individual mussels over time. Translocation occurred on October 10, 2013 with follow-on surveys of the destination sites on June 10, 2014 and September 23, 2014.

3.2 Translocation

Table 3-1 summarizes the source, destination, species, quantity, and life stage of the translocated mussels. The sources for translocated *M. conradicus* and *L. fasciola* are the Clinch River at Kyles Ford and the AWCC, respectively. On October 10, 2013, Don Hubbs (TWRA), Steve Ahlstedt and Craig Walker released 284 adult *M. conradicus* from the Clinch River to the Pigeon River Cosby site and 75 adult *M. conradicus* from the Clinch River to the Nolichucky River at the TWRA Canoe Access (Hubbs, 2014). At that same time, Dr. Michael McKinney (UT) and students translocated 237 sub-adult (27 months) *L. fasciola* (AWCC propagates) to both the Pigeon River Cosby site and the same number to the Nolichucky River at the TWRA

Table 3-1. Source & Destination Information for Tagged Mussels (data extracted from (Hubbs 2014))

Source	Destination	Species	Quantity	Lifestage at Introduction
VDGIF AWCC	Pigeon River – Cosby Site	*L. fasciola*	237	Sub-adults (Age - 2 years, 3 months)
Clinch River at Kyles Ford (Hubbs 2014)	Pigeon River – Cosby Site	*M. conradicus*	284	Adult
VDGIF AWCC	Nolichucky at TWRA Canoe Access	*L. fasciola*	237	Sub-adults
Clinch at Kyles Ford	Nolichucky at TWRA Canoe Launch	*M. conradicus*	75	Adult

*AWCC = AWCC propagates from Clinch stock (Hubbs 2014)

Canoe Access (Hubbs 2014), hereafter "Pigeon River" and "Nolichucky River", respectively, unless further distinction is required. The method of transfer was made via coolers filled with river water and including a battery-powered aeration pump to keep the water oxygenated, thus minimizing stress.

A total of 833 mussels were tagged and translocated in this study. Table A-1 (in Appendix A) provides the initial length and weight for the translocated mussels, with statistics for the same provided in Tables 3-2 and 3-3, respectively. The AWCC retained some *L. fasciola* from the same stock as those translocated. This length is also reported in Table 3-2, i.e., *L. fasciola* (retained). The length of a mussel is measured at the longest part of the shell using calipers (Figure 3-1). The wet weight of the mussels was measured using an OHaus CS 200 scale. The AWCC does not measure the weight of live mussels because of likely inconsistencies in weight due to varying amounts of water in and on a mussel at different measurement times.

Table 3-2. Length of translocated mussels and AWCC retained mussels

Species	Length (mm)				
	Average	Standard Deviation	Min	Median	Max
L. fasciola (translocated)	22.95	3.36	13.11	22.98	30.99
L. fasciola (retained)	13.13	2.71	9.20	12.15	18.30
M. conradicus	37.28	7.38	19.84	37.66	53.54

Table 3-3. Weight of translocated mussels

Species	Weight (g)				
	Average	Standard Deviation	Min	Median	Max
L. fasciola	1.5	1.0	0.04	2.0	4.0
M. conradicus	5.6	3.3	0.04	5.0	16.0

Figure 3-1. Mussel length measurement. Length measurement taken at the longest dimension (Pictured mussel is not *L. fasciola* or *M. conradicus*)

3.3 Housing

At both study sites, translocated mussels were housed in cages or silos, or were released 10-15 meters downstream of the cages and silos (not housed). The silos and cages were used to both protect the mussels and to enable subsequent surveys to find the mussels for data collection. The water depth at time of deployment of the cages and silos was 0.9-1.5 meters and the cages and silos were deployed over 3 meters from each shore by TWRA divers. These placement parameters hold for both the Pigeon and Nolichucky River sites and were required to reduce the risk of vandalism.

Figure 3-2 identifies the source, destination, counts and housing of tagged and translocated mussels. A total of 833 mussels were transferred in this study; 359 *M. conradicus* and 474 *L. fasciola*. Quantities of 75 and 284 *M. conradicus* were transferred to the Nolichucky and Pigeon Rivers, respectively. Half (237) of the *L. fasciola* were transferred to each destination river. In the Nolichucky River, 64 mussels were caged, 80 were in silos, and 168 were distributed from mesh bags. In the Pigeon River, 64 mussels were caged, 80 were in silos, and 377 were distributed from mesh bags.

3.3.1 Silo

Silos (original design by Chris Barnhart, Missouri State University) used in this study (Figure 3-3) are composed of a 10 kg concrete dome and a PVC inner chamber. Within the inner chamber, mussels are contained in standard 1.6-mm mesh fiberglass bags. Covering the inner chamber is a wire mesh with 1-cm^2 openings. Once the chamber is in the concrete dome, a strap is positioned over the PVC to keep the chamber in the silo. The silos were designed such that when water flows over the silo, it creates a Bernoulli effect (Bernoulli, 1738; Streeter, 1966), drawing water up through the mussel enclosure thus providing a supply of water

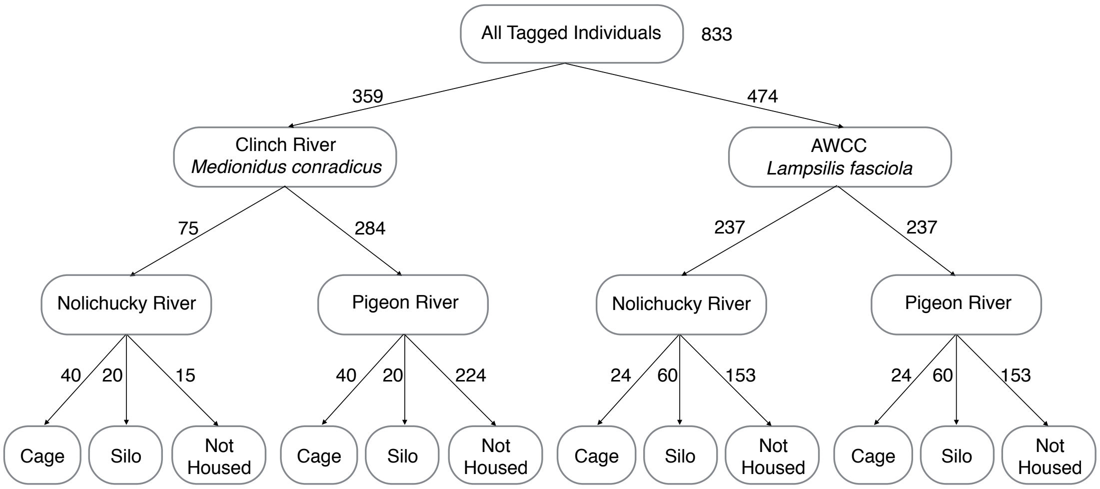

Figure 3-2. Source, destination, counts and housing of translocated mussels

Figure 3-3. Silo. Silo width is 27 cm, height 12 cm, metal opening at top is 8.6 cm in diameter. The interior containing the mussels is 4 cm in diameter and 4 cm in height.

and nutrients to the mussels. The silos also protect the mussels from predators and enable surveyors to easily retrieve them for data collection.

The volume of a silo, $V_s = \pi r^2 h$, where r is the radius of the inner chamber, and h is its height. The silos used in this study have a volume of 50.27 cm^3. This will be useful information to determine the available volume per mussel analyzed.

3.3.2 Cage

Cages used in this study (Figure 3-4) are a PVC pipe (chamber). Within this chamber, mussels are contained in standard 1.6-mm mesh fiberglass bags. Covering both ends of the pipe is a wire mesh with 1 cm^2 openings. The cages were designed to be placed parallel to the ground (laying on the pipe's side), such that water flows through the cage providing a supply of water and nutrients to the enclosed mussels. The cages also protect the mussels from predators and enable easy retrieval for subsequent data collection.

Figure 3-4. Cage. Dimensions of the cage are 9 cm in height and 6.6 cm diameter.

The volume of a cage, $V_c = \pi r^2 h$, where r is the interior radius of the pipe, and h is its height. The cages used in this study have a volume of 307.91 cm^3. This will be used to determine the available volume per mussel.

The numbers of initial mussels placed in the cages and silos, along with their species are provided in Tables 3-4 and 3-5 for the Pigeon and Nolichucky Rivers, respectively. Two cages of 24 *L. fasciola* each and 2 cages of 20 *M. conradicus* each were located in the Pigeon River. Five silos of 12 *L. fasciola* each and 2 silos of 10 *M. conradicus* each were placed in both the Pigeon and Nolichucky Rivers.

Table 3-4. Average cage and silo housing occupants - Pigeon River mussels

House #	Type (Cage or Silo)	# Initial Occupants	Species
S1	Silo	10	*M. conradicus*
C1	Cage	24	*L. fasciola*
C2	Cage	24	*L. fasciola*
S2	Silo	12	*L. fasciola*
S3	Silo	12	*L. fasciola*
C3	Cage	20	*M. conradicus*
C4	Cage	20	*M. conradicus*
S4	Silo	12	*L. fasciola*
S5	Silo	12	*L. fasciola*
S6	Silo	12	*L. fasciola*
S7	Silo	10	*M. conradicus*
Number of Occupants per Housing	Cage: *L. fasciola*: 24 *M. conradicus*: 20	Silo: *L. fasciola*: 12 *M. conradicus*: 10	Total occupants = 168

Table 3-5. Average cage and silo housing occupants - Nolichucky River mussels

House #	Type (Cage or Silo)	# Initial Occupants	Species
S1N	Silo	12	*L. fasciola*
C1N	Cage	20	*M. conradicus*
S2N	Silo	12	*L. fasciola*
C2N	Cage	24	*L. fasciola*
S3N	Silo	10	*M. conradicus*
S4N	Silo	10	*M. conradicus*
S5N	Silo	12	*L. fasciola*
S6N	Silo	12	*L. fasciola*
C3N	Cage	24	*L. fasciola*
S7N	Silo	12	*L. fasciola*
C4N	Cage	20	*M. conradicus*
Number of Occupants per House	Cage: *L. fasciola*: 24 *M. conradicus*: 20	Silo: *L. fasciola*: 12 *M. conradicus*: 10	Total occupants = 168

3.3.3 Mesh Bag Release

A majority of the mussels transferred were released from mesh bags directly onto the substrate. These were placed in shallow (less than 1 meter deep) water, 10-15 meters downstream of the cage and silo locations. Of the translocated mussels, 168 were distributed from mesh bags in the Nolichucky River and 377 were distributed this way in the Pigeon River.

3.4 Water Quality

3.4.1 Chlorophyll-A

Chlorophyll-A is an indicator of nutrient availability. We conducted point water sampling for chlorophyll at the Pigeon River site on May 6, 2014 and the Nolichucky River site on May 15, 2014. Two 1L samples were obtained off the bank at each location, where the water depth was approximately 0.6 meters. Once obtained, the sample was placed in a 4° Celsius cooler for storage and transportation back to the laboratory. Each sample was labelled with "Chl-A", sample date, location, sample indicator (A or B), and the collector's initials.

Upon arrival at the laboratory, we followed the testing protocols of the Turner 10-AU Fluorometer and ran triplicates for each sample. The Fluorometer provides results in fluorescence, and we used the following equation to convert the values to μg/L to calculate the concentration.

$$C = (F * V_a)/V_s$$

where C = Chlorophyll-A concentration (μg/L)

F = Fluorescence Measured

V_a = Volume of acetone used

V_s = Volume of sample filtered

3.4.2 Water Discharge Rate

Water discharge rate (cubic meters per second, m^3/sec) is the only water quality data set available for all sites over the study period. The average and maximum water discharge per month (Figures 3-5 and 3-6, respectively) for the Clinch, Pigeon and Nolichucky Rivers indicate highly variable discharges and maximum discharges exceeding 400 (Clinch and Pigeon rivers) and 500 (Nolichucky River) m^3/s. For each site, the maximum levels occur in December and are variable, yet similar to one another, throughout the year.

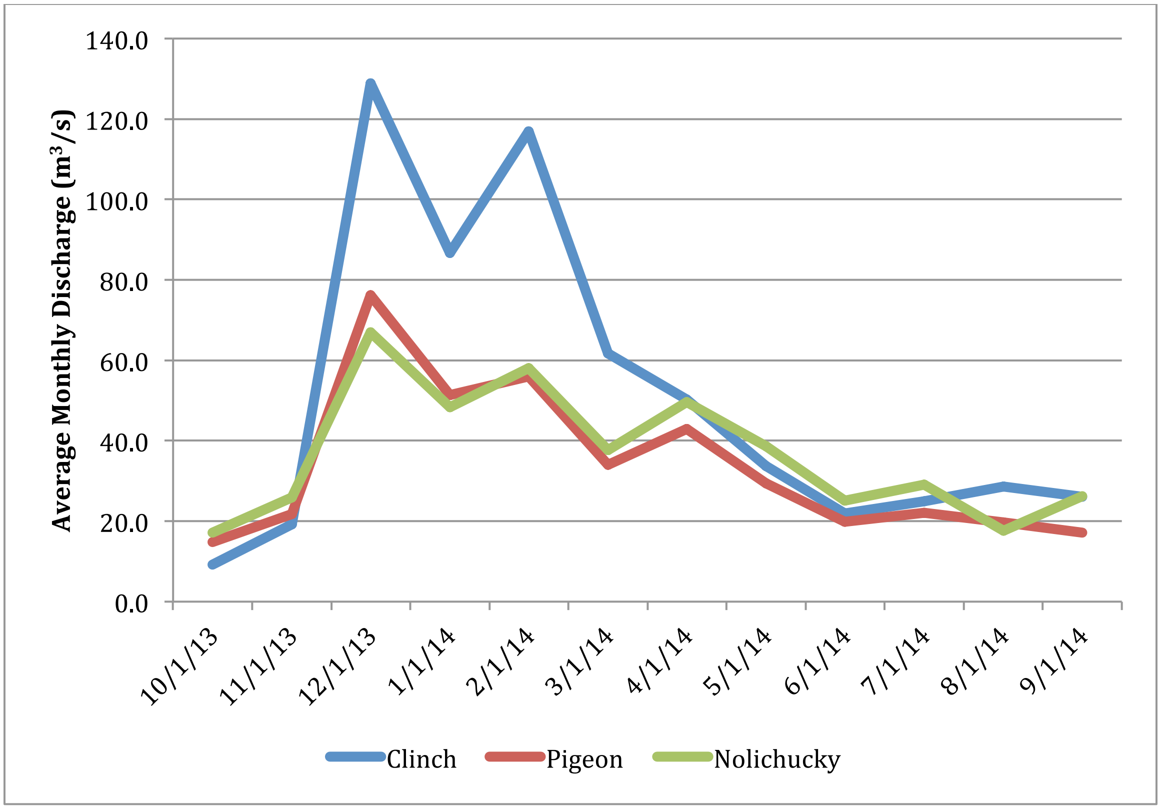

Figure 3-5. Average Monthly Discharge (m^3/s) during the study period for the Clinch, Pigeon and Nolichucky Rivers. Data obtained from http://waterdata.usgs.gov/tn/nwis/inventory; accessed 6/7/2015; USGS Site 03528000 Clinch River above Tazwell, TN; USGS Site 03465500 Nolichucky River at Embreeville, TN; USGS Site 03461500 Pigeon River at Newport, TN.

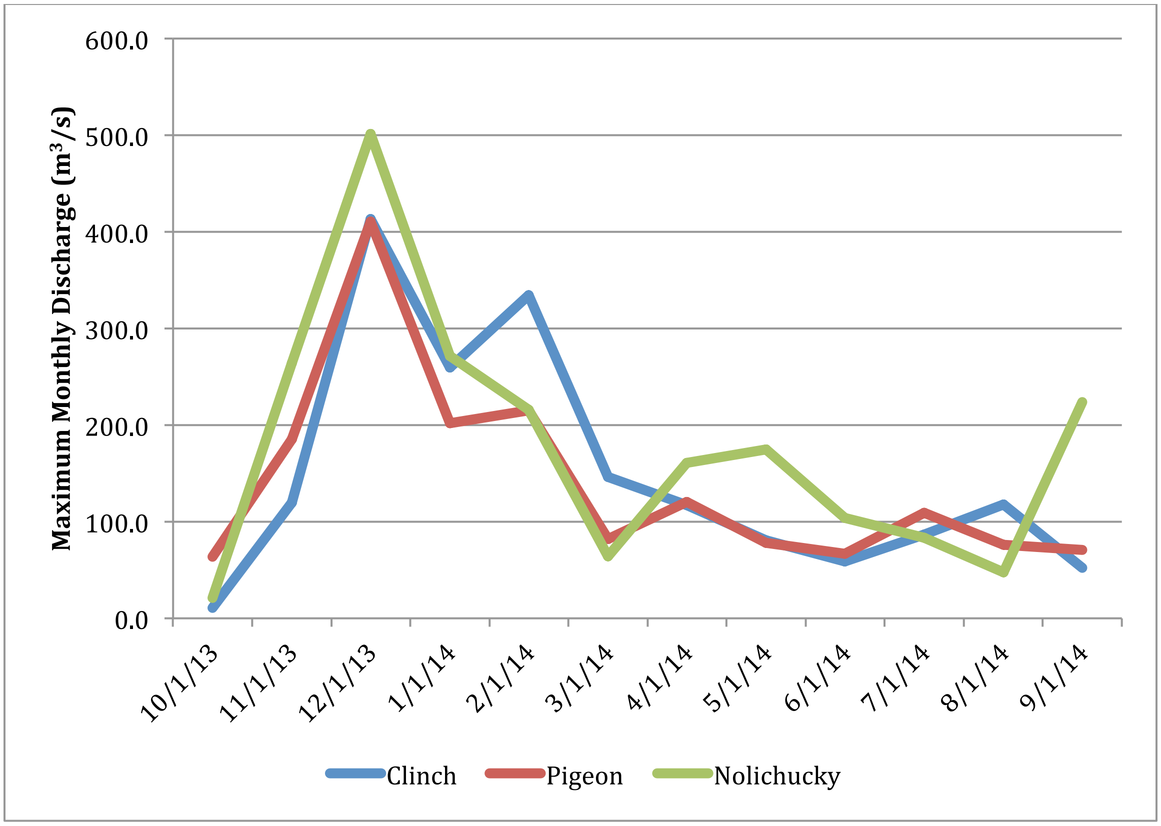

Figure 3-6. Maximum Monthly Discharge (m^3/s) during the study period for the Clinch, Pigeon and Nolichucky Rivers. Data obtained from http://waterdata.usgs.gov/tn/nwis/inventory; accessed 6/7/2015; USGS Site 03528000 Clinch River above Tazwell, TN; USGS Site 03465500 Nolichucky River at Embreeville, TN; USGS Site 03461500 Pigeon River at Newport, TN.

3.5 Surveys

Follow-on surveys were conducted on June 10, 2014 and September 23, 2014. Wet suits and breathing apparatus (scuba or snorkel) were used in the search for the cages and silos. The housings were placed in coolers with river water and aerating pumps. Cages were brought to shore individually for measurement to minimize the time the mussels were out of their habitat. After measurement, each housing was returned to the river and placed in its original position.

3.6 Data Collected and Analyzed

Data were collected for each mussel recovered, including

- Tag number,
- River,
- Species (equates to source in this study),
- Housing (cage, silo or mesh bag release),
- Length (live mussels) (mm),
- Weight (live mussels) (g),
- Condition of housing (in terms of silt), and
- Life status (live, dead).

The first and third surveys were full surveys, whereas the second survey analyzed a reduced sample of the relocated mussels as we did not want to disturb all the specimens but were just checking on the general status of the experiment. Basic descriptive statistics were calculated (using Microsoft Excel® (2010)) for each individual data type and more complex models (Section 3.8) were required to evaluate the significance of the effects of these factors on growth and survival.

3.7 Recovery Rate and Effort

Members of the TWRA (Tennessee Wildlife Resources Agency) and several of Dr. Michael McKinney's undergraduate students accompanied the author on the final survey. The Catch per Unit Effort (CPUE) is calculated as follows. The recovery rate, R, is the number of mussels recovered during the i^{th} survey (n_i) divided by the number of mussels originally transferred to the location (n_0). The CPUE is the number of mussels recovered during the i^{th} survey (n_i) divided by the effort, e, (in person-hours) to capture those mussels, measured in mussels per person-hour.

$R = n_i / n_0,\ 0.0 \leq R \leq 1.0$

$CPUE = n_i / e,\ CPUE \geq 0.0$

3.8 Analyzing Survival and Growth Rate

Survival is calculated as the number of mussels alive at the end of the study divided by the number of mussels translocated, i.e., $\text{Mussels}_{\text{live}}/\text{Mussels}_{\text{total}}$. Both absolute growth rate and relative growth rates (AGR and RGR, respectively) are evaluated. 30-day absolute growth rate (AGR_{30}) is calculated as follows:

$$\text{AGR}_{30} = \left({(l_{end} - l_{begin})}/{m} \right) * 30$$

where m = number of days in the study, 348 for the current study, and

l = length (mm)

AGR_{30} units are mm per 30 days.

RGR_{30} is the growth rate relative to the mussel's initial size. It is a fractional value, which if multiplied by 100 provides the percent relative growth rate. RGR_{30} is calculated as follows:

$$\mathrm{RGR}_{30} = \left(\left(\frac{l_{end} - l_{begin}}{l_{begin}}\right) \div m\right) * 30$$

A mixed model analysis of variance (ANOVA) is used to test for significance of combined effects of river site, housing type and time on mussel survival and growth rate. Generalized mixed models (Saxton, 2013) were implemented using the SAS Statistical Software, version 9.4 (SAS, 2013) GLIMMIX procedure. The treatments analyzed (Table 3-6) are River, Species, Housing and Time. An example treatment is: *L. fasciola* housed in a Silo in the Pigeon River measured on 10/10/2013.

Table 3-6. Study Design

Class	**Levels**	**Values**
Destination River	2	Pigeon Nolichucky
Species	2	*L. fasciola* *M. conradicus*
Housing	2	Silo Cage
Time	3	10/10/2013 6/10/2014 9/23/2014

For survival rate, a randomized block design (RBD) is used with the dependent variable, Survival Rate (SR). The effects of Destination River, Species, Housing and Time are examined in this full model. In addition, separate models were developed for each species. For the species-specific models, the dependent variable is the survival rate, and the effects of Destination River, Housing and Time are examined. The SAS PROC GLIMMIX was used for all models in this study. Other specifics of the survival models include:

- Normality of the residuals is assumed.
- Variance/covariance type=vc (variance components) is used. On the RBD repeated measures designs, variance/covariance type=ar(1) did not offer a significant enough improvement in AIC (the Akaike Information Criterion (Akaike, 1973)) to warrant its selection.
- Kenward Roger degrees of freedom adjustments were used for the type III tests for fixed effects.
- Bonferrnoni adjusted p-values were used in the LS-means post hoc tests.
- The modeling equations regarding fixed and random effects follow classic techniques for RBD designs, split plot and split-split plot designs.
- Wald covariance parameter tests were used to determine whether the covariance parameters were different from zero.

For growth rate, a complete randomized design (CRD) is used with the dependent variable 30 day [Absolute | Relative] Growth Rate. As in the SR models, the full model examines the effects of the destination river, species, housing, and time on growth rate with separate models developed for each species. The SAS PROC GLIMMIX was used for the growth rate models in this study. Additional specifics of the growth rate models include:

- Variance/covariance type=vc (variance components) was used for most models.
- Kenward Roger degrees of freedom adjustments were used for the type III tests for fixed effects.
- Bonferrnoni adjusted p-values were used in the post hoc tests where necessary.
- The modeling equations regarding fixed and random effects follow classic techniques for CRD designs, split plot and split-split plot designs.
- The Wald covariance parameter tests were used to determine whether the covariance parameters were different from zero.

CHAPTER 4

RESULTS

4.1 Interim Survey Results

The interim survey of the Pigeon and Nolichucky sites took place on June 10, 2014. The purpose of this survey was to check the status of the mussels, examine a sample, and collect data on that sample. Table A-2 provides the length and weight data collected in the interim survey. Table 4-1 summarizes the length, weight and survival data collected on the 100 live *L. fasciola* and 37 live *M. conradicus* tagged individuals recovered during this survey.

Table 4-1. Summary of interim survey, 6/10/2014. Length and weight are measured for live mussels only.

Species	**Length (mm)**				
	Average	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola	25.75	3.04	18.75	25.83	34.73
M. conradicus	34.20	8.04	24.31	33.47	45.79
	Weight (g)				
	Average	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola	2.65	1.08	0.6	2.7	6.4
M. conradicus	4.71	2.91	1.9	3.3	10.9
	Survival				
	Live	**Dead**	**Total**	**Survival Rate**	
L. fasciola	95	5	100	0.95	
M. conradicus	16	21	37	0.43	

4.2 Final Study Survey

A full survey of the Pigeon and Nolichucky sites was conducted on September 23, 2014. Table A-3 provides the length and weight data collected in this survey, while

Table 4-2 summarizes the length, weight and survival data collected on the 168 *L. fasciola* and 120 *M. conradicus* found.

Table 4-2. Summary of final survey, 9/23/2014. Length and weight are measured for live mussels only.

Species	**Length (mm)**				
	Average	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola	31.87	5.81	19.08	31.99	58.97
M. conradicus	40.56	6.95	25.31	42.22	50.92
	Weight (g)				
	Average	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola	5.32	2.50	1.3	5.0	13.9
M. conradicus	6.61	3.04	1.0	6.5	12.7
	Survival				
	Live	**Dead**	**Total**	**Survival Rate**	
L. fasciola	149	19	168	0.89	
M. conradicus	56	64	120	0.47	

4.3 Recovery Rate and Effort

Members of the TWRA (Tennessee Wildlife Resources Agency) and University of Tennessee (UT) undergraduate students of Dr. Michael McKinney accompanied the author on the September 23, 2014 survey. Overall, 35% of the 833 total relocated mussels were recovered (Table 4-3). The recovery rate for *L. fasciola* and *M. conradicus* were 35% and 33%, respectively, of the total mussels released. Recovery rate by river was 28% and 46%, respectively, for the Pigeon and Nolichucky Rivers. None of the mussels released from bags were recovered and no significant concentration of dead shells of *L. fasciola* or *M. conradicus* were found. All relocated mussels placed in cages or silos were recovered for analysis.

Table 4-3. Recovery rate

		Species		Site		Housing		
		L. fasciola	***M. conradicus***	**Pigeon River**	**Nolichucky River**	**Cage**	**Silo**	**Bag Release**
Species	***L. fasciola***	0.35						
	M. conradicus		0.33					
Site	**Pigeon River**	0.48	0.08	0.28				
	Nolichucky River	0.36	0.61		0.46			
Housing	**Cage**	1.00	1.00			1.00		
	Silo	1.00	1.00				1.00	
	Bag Release	0.00	0.00					0.00
L. fasciola	**Pigeon River**					1.00	1.00	0.00
	Nolichucky River					1.00	1.00	0.00
M. conradicus	**Pigeon River**					1.00	1.00	0.00
	Nolichucky River					1.00	1.00	0.00
Overall	**0.35**							

Of those participating in the survey, 4 participants were assigned to the recovery effort, while others weighed and measured the recovered individuals. Table 4-4 describes the catch per unit effort (CPUE) of mussels in the study, with an overall CPUE of 12.0, the Nolichucky at 14.4 and the Pigeon with a CPUE of 10.3.

Table 4-4. Catch per Unit Effort

Metric	**Pigeon**	**Nolichucky**	**Total**
Time spent on recovery (hours)	3.5	2.5	6
No. persons on recovery	4	4	8
Total person-hours	14	10	24
No. mussels recovered	144	144	288
CPUE	10.3	14.4	12.0

Unit Effort = 1 person-hour

4.4 Survival

4.4.1 Descriptive Statistics

The survival rate (*N* Live/*M* Recovered) of species over the study time (Figure 4-1) shows a steeper slope of decline for *M. conradicus*. There is very little difference between the destination rivers in terms of survival rate (SR) (Figure 4-2).

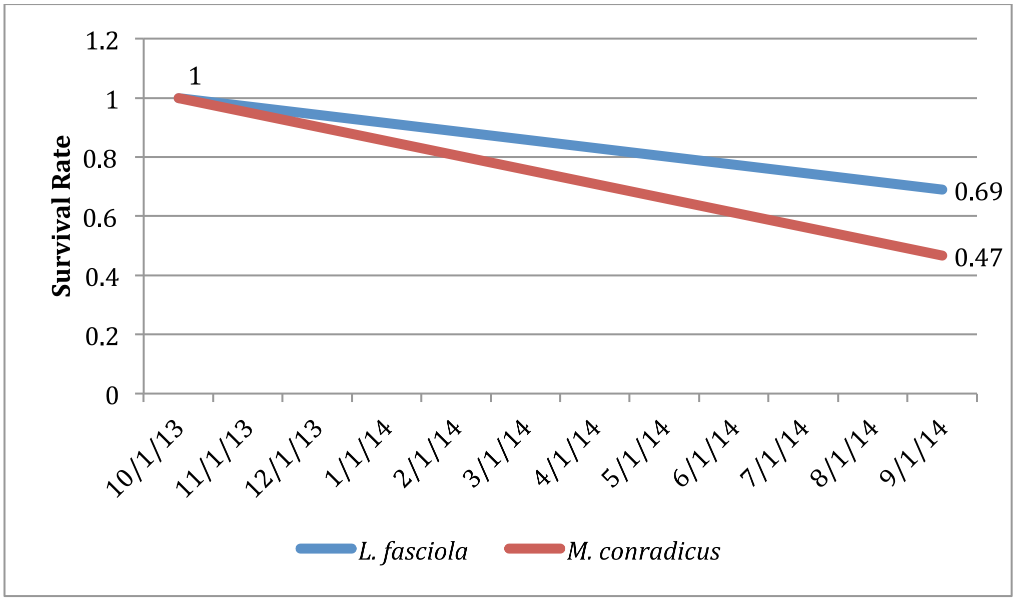

Figure 4-1. Survival by Species over Time

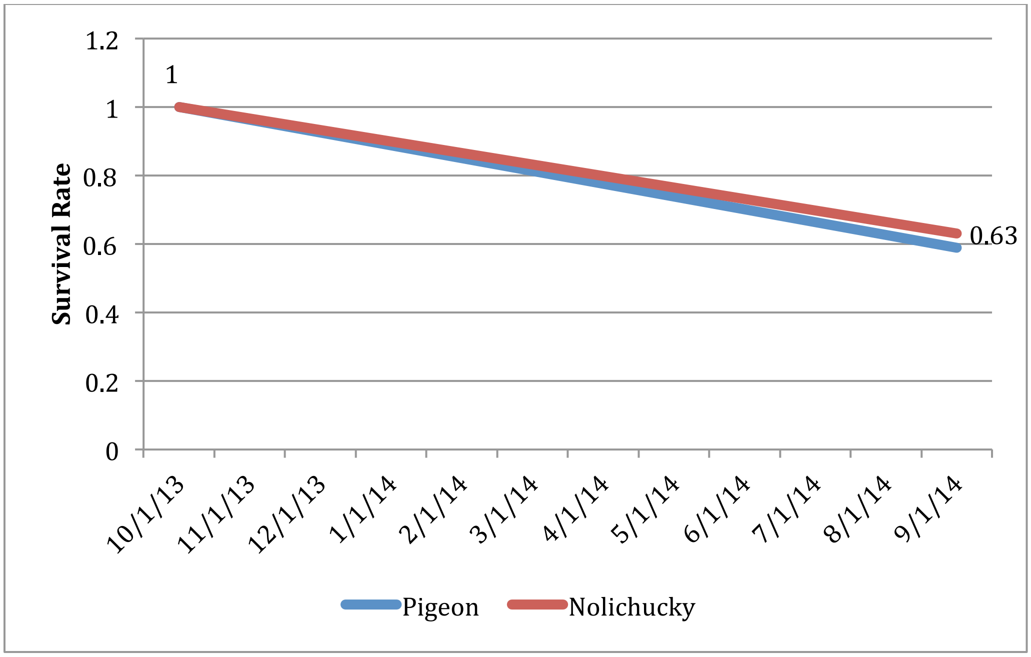

Figure 4-2. Survival by River over Time (values shown for Nolichucky River)

The AWCC held back a sample of *L. fasciola* juveniles of the same age and stock as those used in this study. Figure 4-3 presents the SR over time for *L. fasciola* in the Pigeon River, Nolichucky River and those held by AWCC. The AWCC held mussels had the highest survival with all mussels surviving. The Pigeon River provided slightly higher SR for *L. fasciola* than did the Nolichucky River. The SR for *M. conradicus* was higher in the Nolichucky (Figure 4-4).

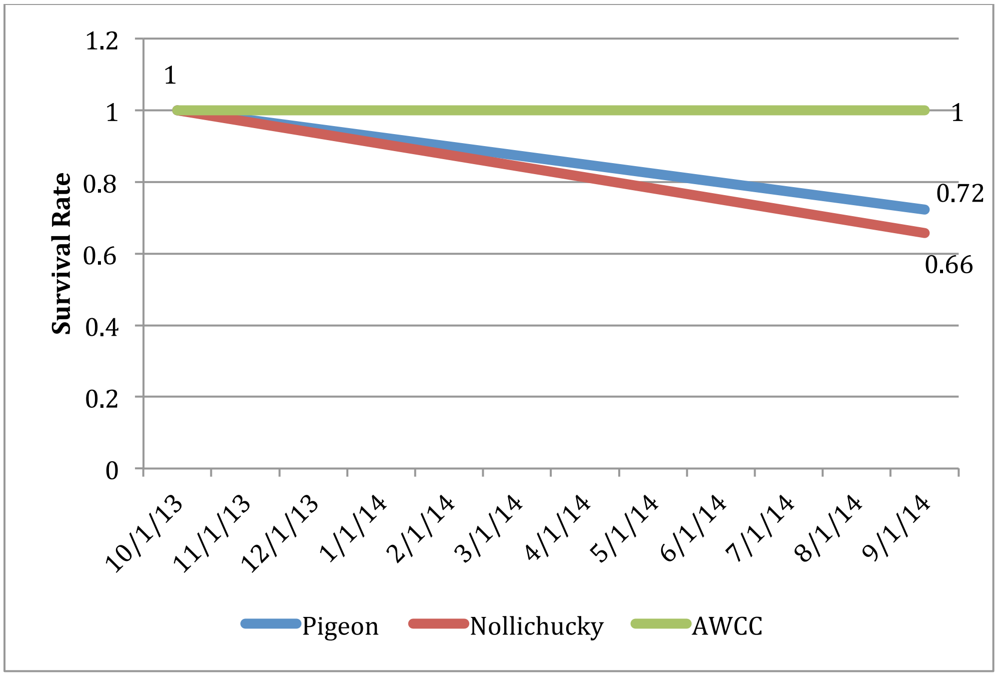

Figure 4-3. ***L. fasciola*** **Survival by Destination**

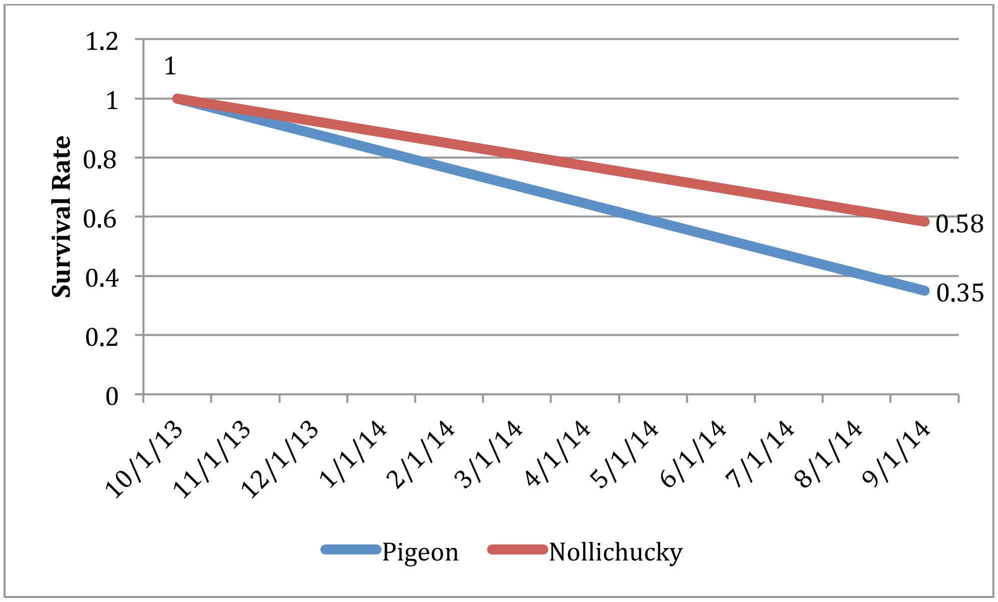

Figure 4-4. ***M. conradicus*** **Survival by Destination**

If we examine SR and housing type (Figure 4-5), we see little difference in SR between cages and silos at the final survey. Housing condition was noted on the last survey. I categorize housing condition based on the proportion of silt in the housing as follows: clear/no silt (0), light silt/less than 10% silted (1), moderately silted/[10% < silt by volume < 50%] (2), and heavily silted/more than 50% silt by volume (3). Those few with housing condition 3 were 90-100% silted. SR by housing condition (Figure 4-6) shows greater than 80% survival for those mussels in housing of conditions 0-2 and less than 20% survival for those mussels in housing of condition 3 (heavily silted). This finding supports the finding that extremely highly silted housing (Cond 3) was responsible for the deaths of the mussels housed therein.

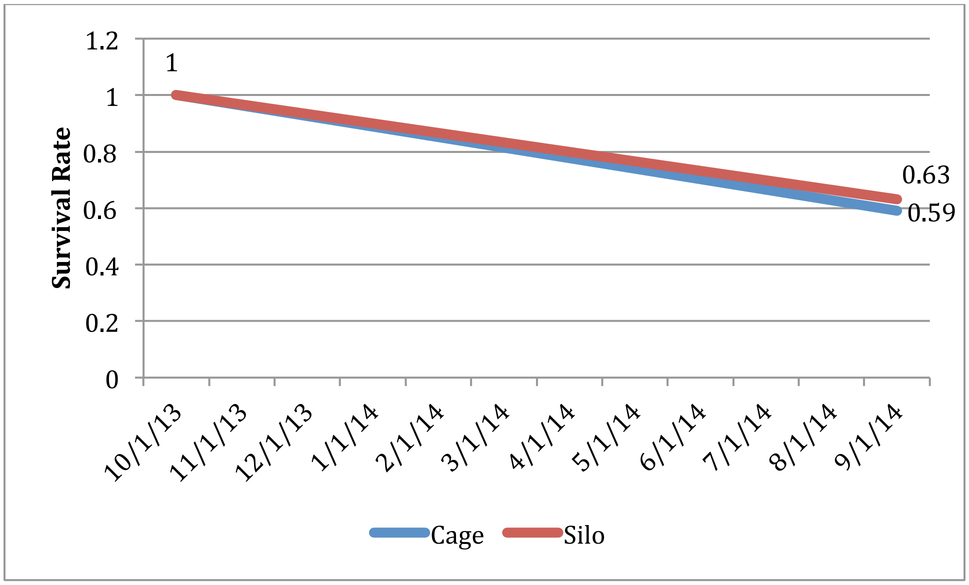

Figure 4-5. Survival by Housing

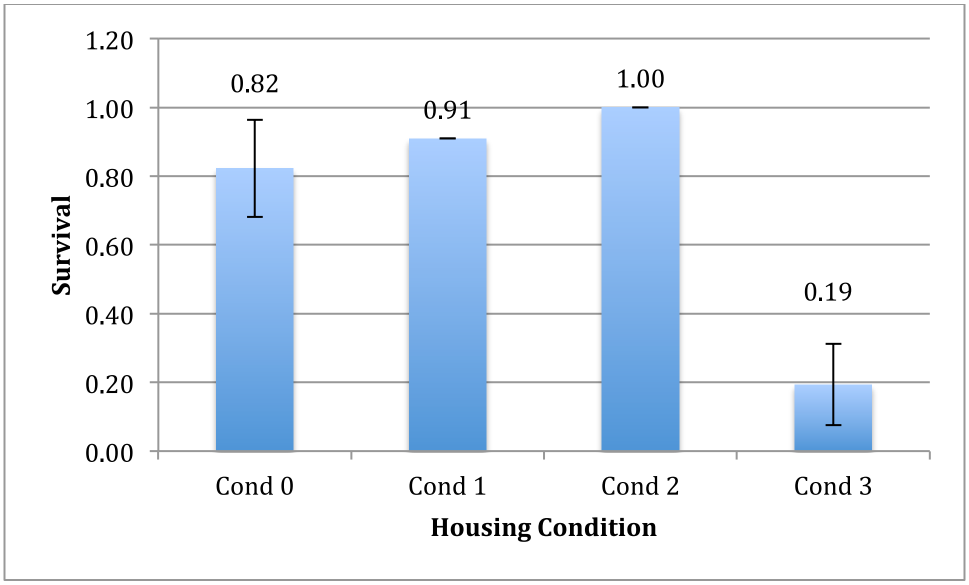

Figure 4-6. Survival by Housing Condition

I used Pearson's correlation coefficient to determine if there were any correlation between the volume available per mussel and survival for the following: within each species, within each river, and within each container. The maximum correlation was 0.36. Figure 4-7 illustrates survival by volume for each species and given the large standard deviation on many points and the small number of replicates, more data are needed to examine this relationship further. This evaluation does not take into account the reduced volume available to each mussel because of increased siltation.

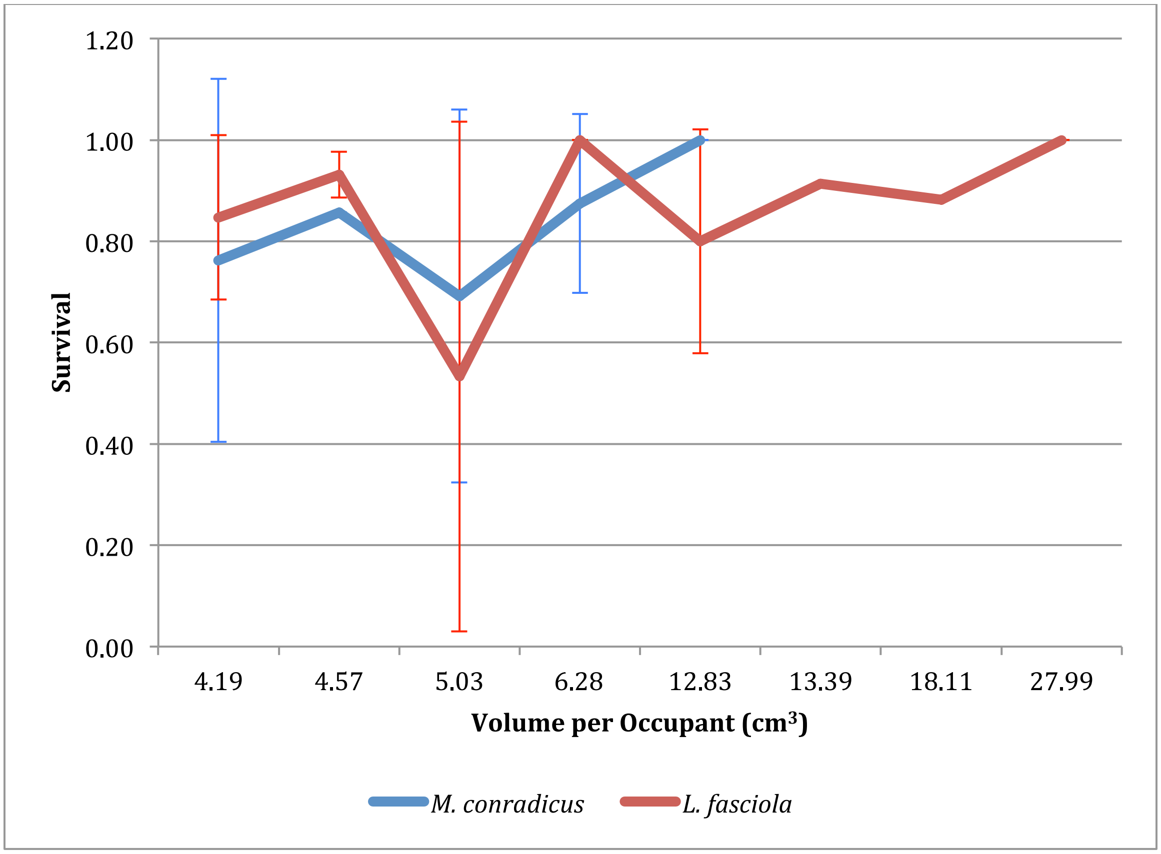

Figure 4-7. Survival by Volume per Occupant.

4.4.2 Model-Based Analysis of Survival

As noted in the Methods, I used a Mixed Model ANOVA (split-split plot) for survival with model inputs provided in Table B-1 (Appendix B). The assumptions for this model are met (see Table B-5) with normality of the model residuals (Figure B-4) and no outliers in the residuals. There is equality of variance between the treatment conditions.

The Destination River was shown not to be statistically significant to mussel survival, with Pr>0.05 (Table B-3). This means that, in this study, mussel survival is not influenced by River: the Pigeon River is not different than the Nolichucky in terms of overall mussel survival. In addition, the covariance for Destination is not different from 0.0, meaning that all variances due to Destination river are explained by the model. Given these results, the full model is blocked on river. The full model ANOVA table is shown in Table 4-5.

Table 4-5. Full Survival Model ANOVA

Source	Error	Degrees of Freedom (DoF) (numerator)	DoF (denominator)
Wp	B*Wp	1	2
Sp	B*Wp*Sp	1	2
SSp	B*Wp*Sp*SSp	2	8
Wp*Sp	B*Wp*Sp	1	2
Wp*SSp	B*Wp*Sp*SSp	2	8
Sp*SSp	B*Wp*Sp*SSp	2	8
Wp*Sp*SSp	B*Wp*Sp*SSp	2	8

where B = Block, in this case on Destination
Wp = Whole plot, Species

Sp = Split plot, House
SSp = Split-split plot, Time

The full model reveals that the Time (of survey) effect on Survival is the most significant (Table B-2). The Time effect is statistically significant and the effects at each survey time are statistically different (Table B-3, Figure B-1). The model also reveals that the House*Time combined effect is significant (Table B-4, Figure B-2).

To provide additional assurance that the Destination River is not a significant factor (in this study) in mussel survival, I examine split plot models for each species. That is, I prepared 2 additional models – one for *L. fasciola* and the effects on its survival, and a separate model for *M. conradicus* and the effects on its survival. The species-specific model ANOVA table is shown in Table 4-6. The model assumptions (of no severe outliers, normality, and equality of variance) are met for both the *L. fasciola* and *M. conradicus* models (Tables B-6 and B-7). All variability is accounted for in each species-specific model with overall and destination covariances not different than 0. The *L. fasciola* model indicates that Time is a very significant factor on *L. fasciola* Survival and the House*Time interaction is significant (Table B-8). The *M. conradicus* model indicates that Time and the House*Time interaction are significant factors on *M. conradicus* survival (Table B-9).

Table 4-6. Species-Specific Survival Model ANOVA

Source	**Error**	***L. fasciola***		***M. conradicus***	
		Num DoF	**Den DoF**	**Num DoF**	**Den DoF**
Wp	B*Wp	1	5	1	1
Sp	B*Wp*Sp	2	5	2	4
Wp*Sp	B*Wp*Sp	2	5	2	4

where B = Block, on Destination
Wp = Whole plot, House
Sp = Split plot, Time

4.5 Growth Rate

This section presents results of analyzing absolute and relative growth rate. Note that only live mussels were measured and used in these analyses.

4.5.1 Descriptive Statistics

Absolute Growth Rate

The 30-day absolute growth rate (AGR_{30}) of species over the study time (Table 4-7) shows a higher AGR_{30} for *L. fasciola* (Figure 4-8) over *M. conradicus* (Figure 4-9), at 0.80 mm and 0.29 mm, respectively. Average AGR_{30} is higher in the Nolichucky although the Pigeon River mussels exhibit the greatest maximum AGR_{30}.

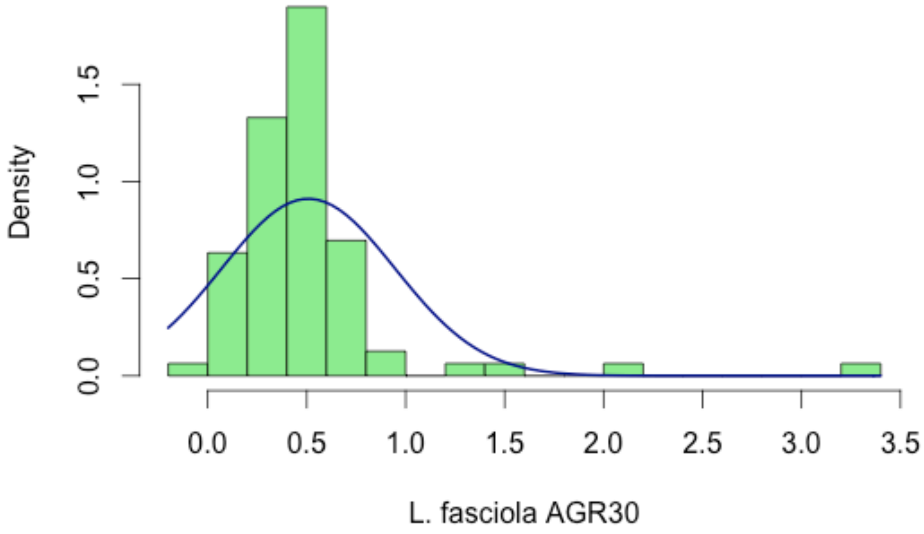

Figure 4-8. *L. fasciola* 30-day Absolute Growth Rate. The growth rate density is shown with the data's Normal curve.

Table 4-7. Summary of Absolute Growth Rate.

AGR (mm/30days)					
Species	**Average**	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola	0.80	0.48	-1.60	0.72	3.28
M. conradicus	0.29	0.47	-0.09	0.28	1.49
River	**Average**	**Std Dev**	**Min**	**Median**	**Max**
Pigeon	0.43	0.48	-1.6	0.43	3.28
Nolichucky	0.88	0.48	-0.61	0.97	1.93
Species & River	**Average**	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola					
Pigeon	0.51	0.44	-0.09	0.45	3.28
Nolichucky	1.10	0.32	-0.08	1.13	1.93
AWCC	0.65	0.28	0.11	0.67	1.17
M. conradicus					
Pigeon	0.11	0.51	-1.60	0.06	1.12
Nolichucky	0.39	0.41	-0.61	0.47	1.49
Housing Type	**Average**	**Std Dev**	**Min**	**Median**	**Max**
Silo	0.73	0.49	-0.61	0.62	3.28
Cage	0.60	0.56	-1.60	0.51	2.16
Species & House	**Average**	**Std Dev**	**Min**	**Median**	**Max**
L. fasciola					
Silo	0.81	0.49	-0.09	0.72	3.28
Cage	0.78	0.49	0.11	0.66	2.16
M. conradicus					
Silo	0.37	0.33	-0.61	0.47	0.83
Cage	0.25	0.53	-1.60	0.15	1.49

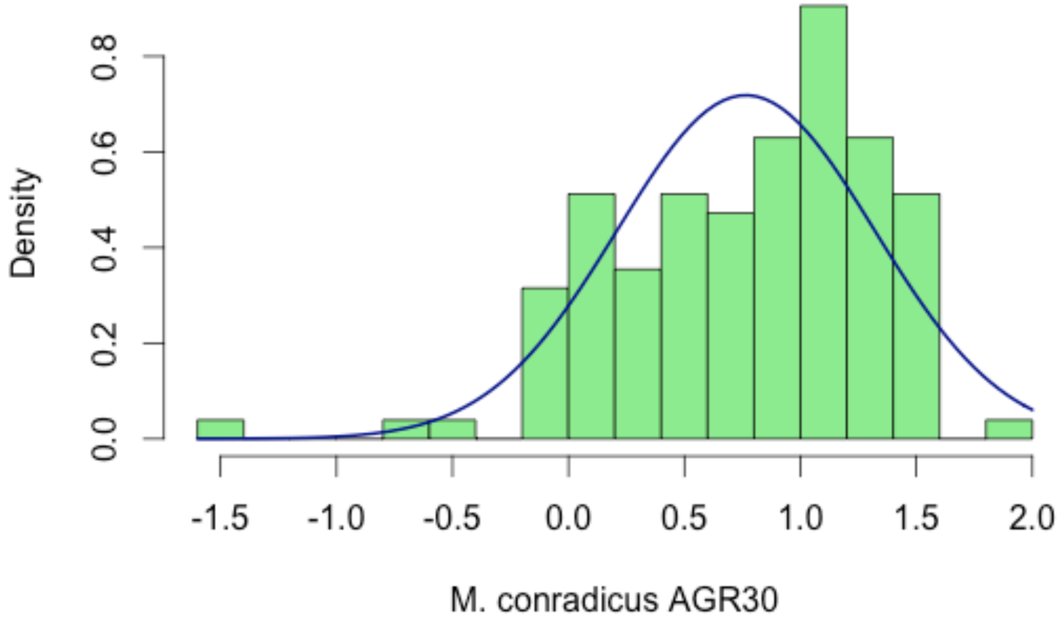

Figure 4-9. ***M. conradicus* 30-day Absolute Growth Rate.** The growth rate density is shown with the data's Normal curve.

As noted, the AWCC held back a sample of *L. fasciola* juveniles of the same age and stock as those used in this study as a control group. Table 4-2 includes the AGR_{30} for *L. fasciola* in the Pigeon River, Nolichucky River and held by AWCC. The AWCC held mussels had more consistent growth than those in the Pigeon and Nolichucky. The Nolichucky River provided the highest AGR_{30} for both species (Figure 4-10). AGR_{30} by housing (Figure 4-11) shows higher AGR_{30} in silos, however the difference in average AGR_{30} between cages and silos is 0.13mm per 30 days.

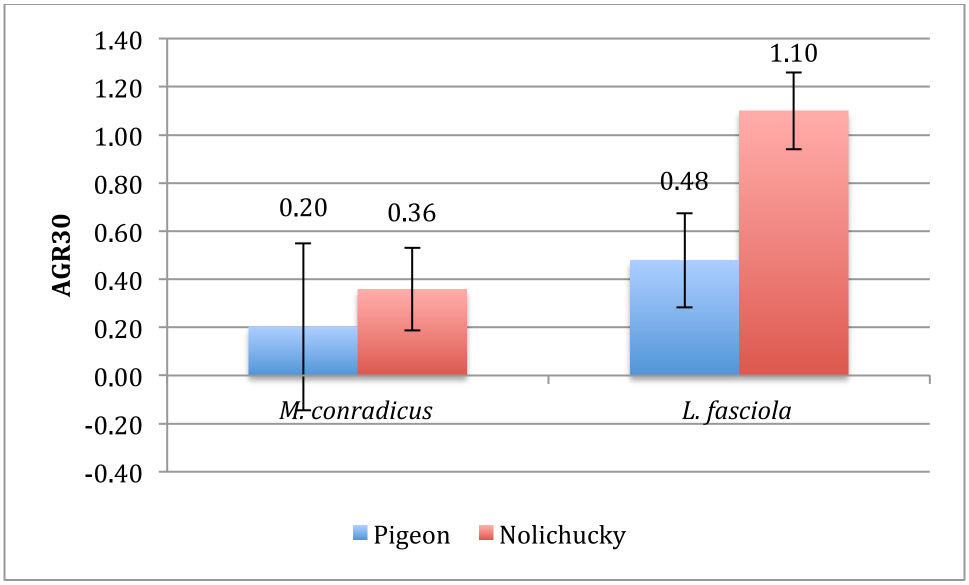

Figure 4-10. Absolute Growth Rate by River

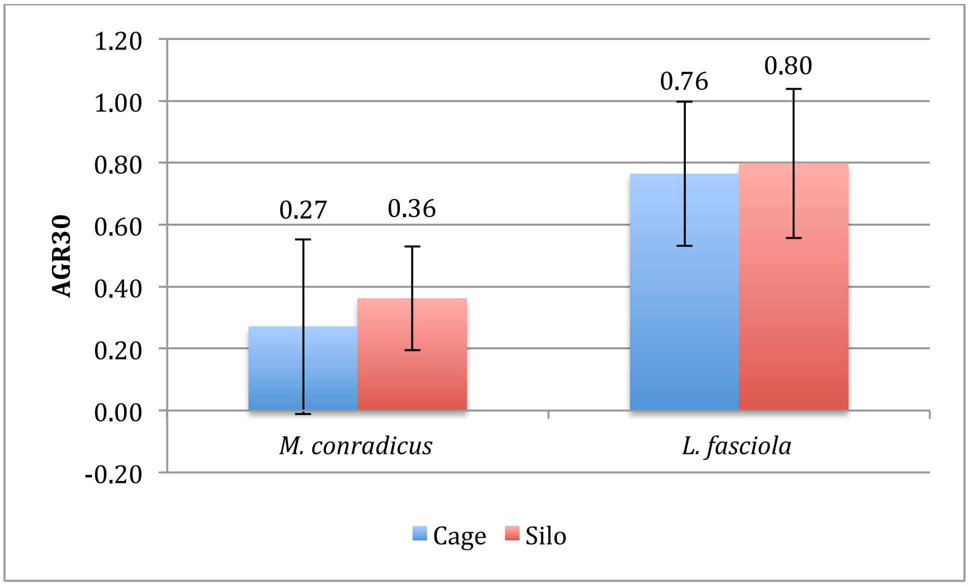

Figure 4-11. Absolute Growth Rate by Housing

Figure 4-12 depicts AGR_{30} by housing condition and illustrates a different pattern than does survival by housing condition. Whereas the lowest survival exists for mussels in housing condition 3 (heavily silted), those same mussels exhibited the highest growth rate at 0.85mm per 30 day period. In addition, there is no correlation between AGR_{30} and available volume per mussel in the housing for the time period considered (348 days).

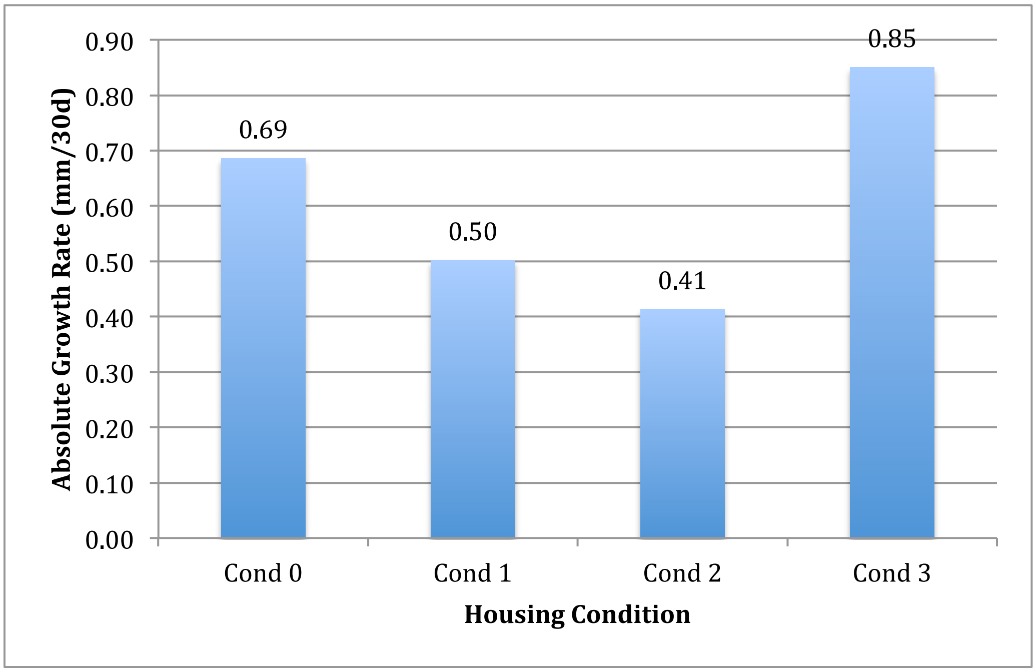

Figure 4-12. 30-day Absolute Growth Rate by Housing Condition

Relative Growth Rate

The 30-day relative growth rate (RGR_{30}) of species over the study time shows a higher RGR_{30} for *L. fasciola* (Figure 4-13) over *M. conradicus* (Figure 4-14), at 3.5% and 0.96%, respectively. Average RGR_{30} is higher in the Nolichucky.

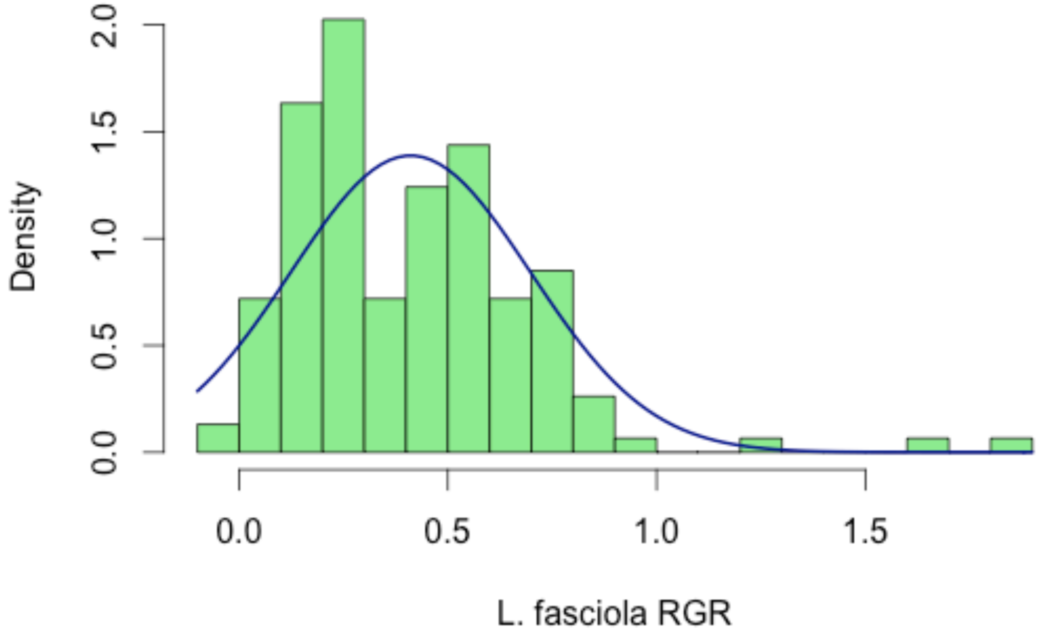

Figure 4-13. ***L. fasciola*** **Relative Growth Rate (30 d)**

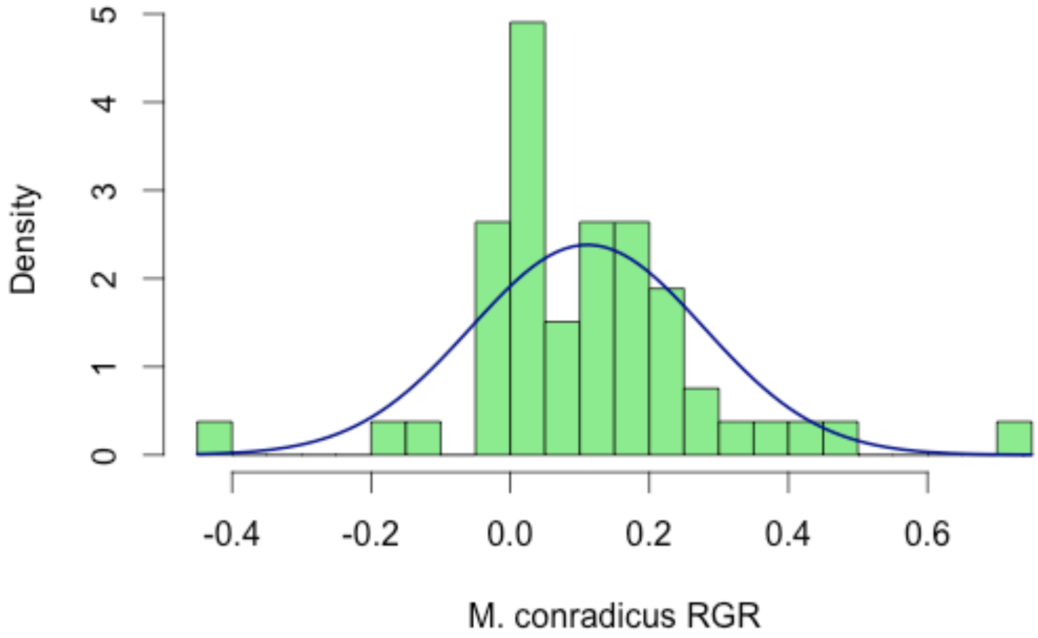

Figure 4-14. ***M. conradicus*** **Relative Growth Rate (30 d)**

The RGR_{30} for *L. fasciola* in the Pigeon River, Nolichucky River and those held by AWCC reveals that the AWCC held mussels had no negative relative growth rates, whereas those in the Pigeon and Nolichucky did. The Nolichucky River provided the highest RGR_{30} for *L. fasciola*, where both rivers had the same growth rate for *M. conradicus* (Figure 4-15). RGR_{30} by housing (Figure 4-16) shows higher RGR_{30} in silos, however the difference in average RGR_{30} between cages and silos is less than 1.0% over 30 days. Figure 4-17 depicts RGR_{30} by housing condition and illustrates a different pattern than does absolute growth rate by housing condition with shrinkage existing only in the relative growth rate for mussels in condition 3 housing (heavily silted). All of the heavily-silted housings were in the Nolichucky River. In addition, there is no correlation between RGR_{30} and available volume per mussel in the housing. It is expected, however, that there will be such a correlation upon subsequent surveys, given the mussels' expected potential growth.

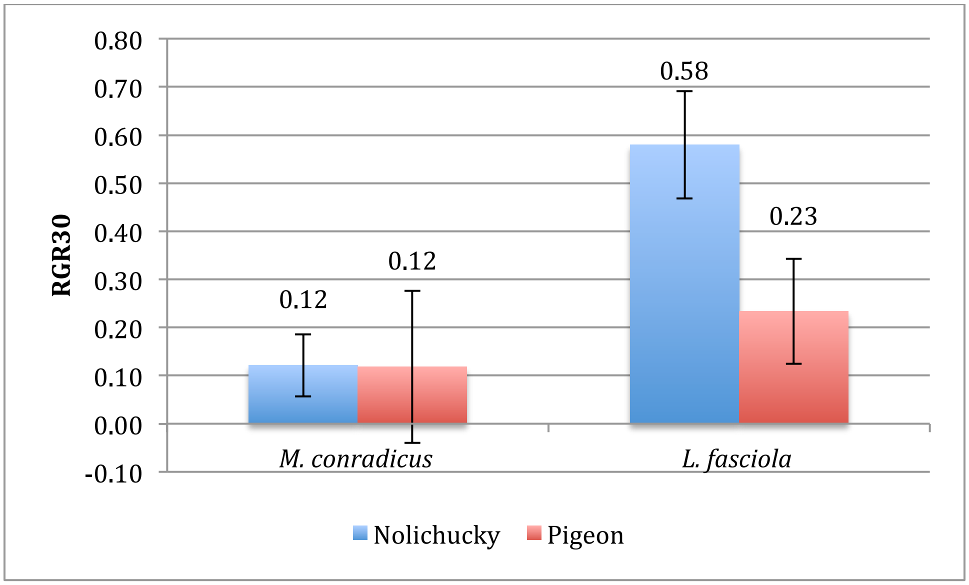

Figure 4-15. RGR30 by River

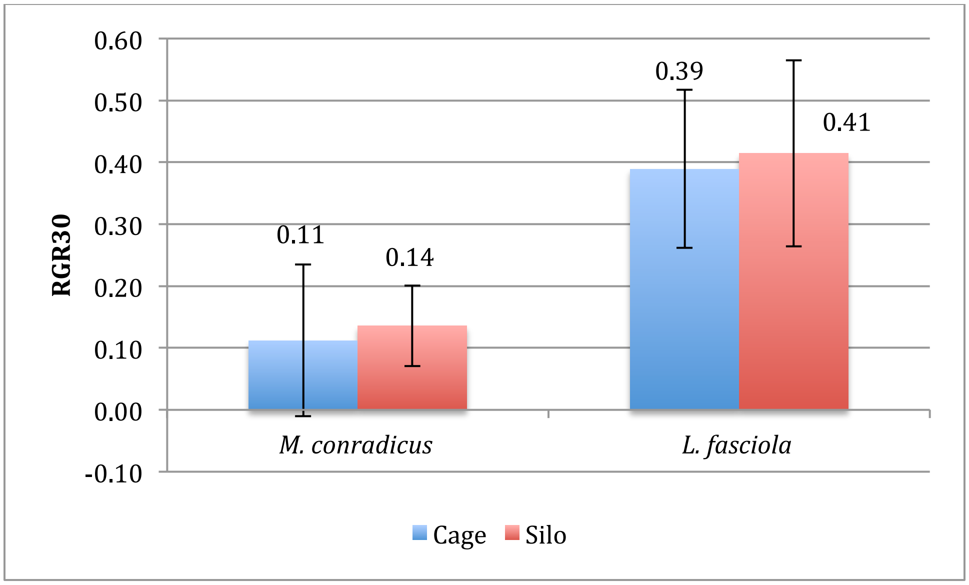

Figure 4-16. RGR30 by Housing

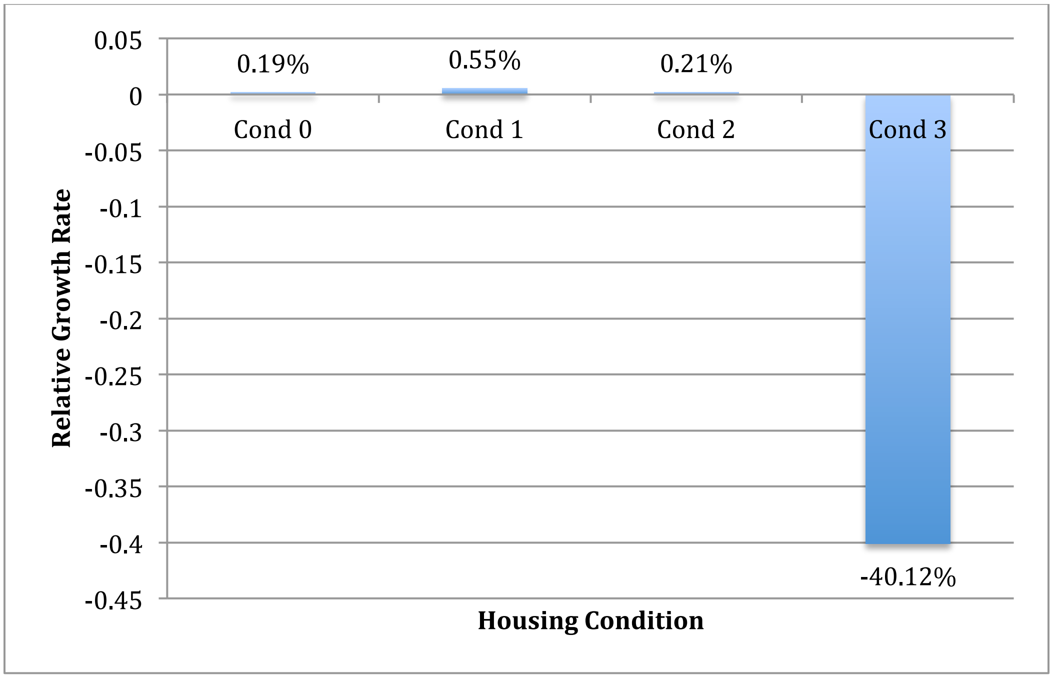

Figure 4-17. 30-day Relative Growth Rate by Housing Condition

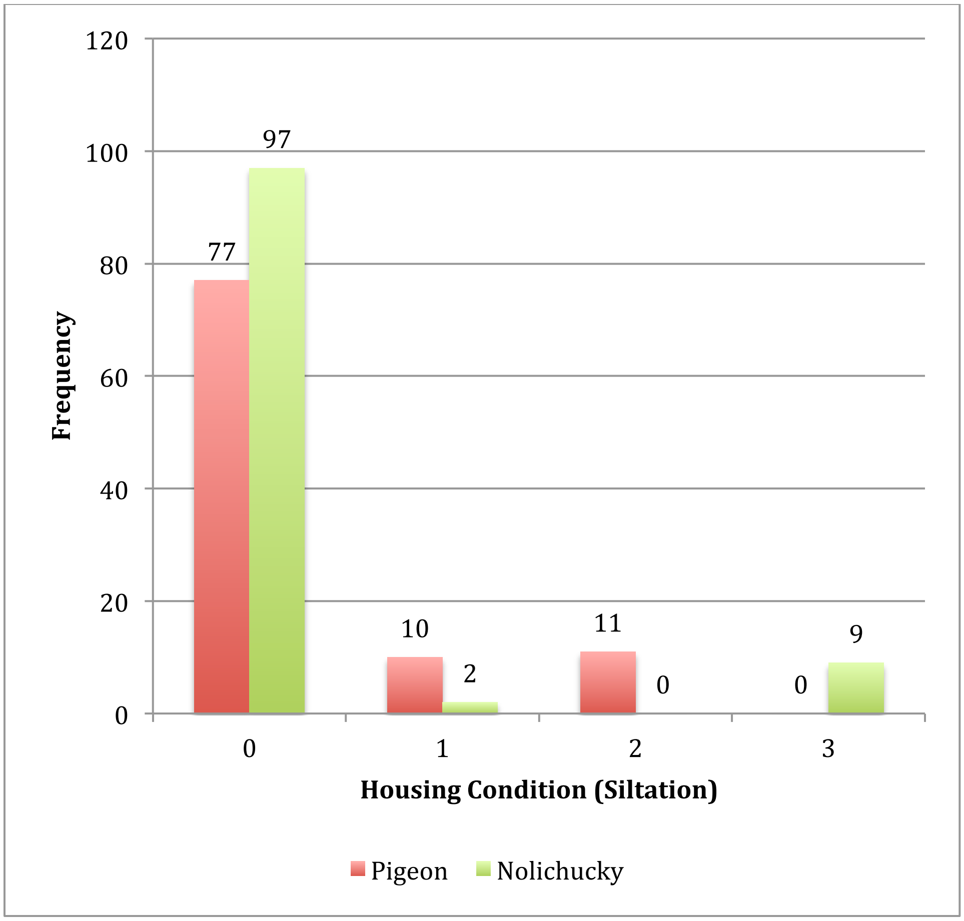

Figure 4-18. Housing Condition by Destination River

4.5.2 Model-Based Analysis of Growth Rate

Absolute Growth Rate

To analyze the factors that influence growth rate, I used a Mixed Model ANOVA, (Table C-3) (Appendix C) with model data shown in Table C-1 and summarized in Table C-2. The dependent variable is Absolute Growth Rate and I examined the effects of Destination River, Species, and Housing (Table C-4). The assumptions for this model are met with normality of the model residuals (Figure C-3) and the conditional residuals (Figure C-9). The full model ANOVA table is shown in Table 4-8.

Table 4-8. Full Absolute Growth Rate Model ANOVA

Source	Error	DoF (numerator)	DoF (denominator)
Wp	R(Wp)	1	97
Sp	Sp*R(Wp)	1	41
SSp	SSp*Sp*R(Wp)	1	41
Wp*Sp	Sp*R(Wp)	1	85
Wp*SSp	SSp*Sp*R(Wp)	1	85
Sp*SSp	SSp*Sp*R(Wp)	1	85
Wp*Sp*SSp	SSp*Sp*R(Wp)	1	85

where Wp = Whole plot, Destination

Sp = Split plot, Species

SSp = Split Split plot, House

R = Reps

The model determines that all 2-way effects are statistically significant for both species (Table C-4). Table C-5 provides the mean separation for 30-day Absolute Growth Rate in mm (AGR_{30}), which is used to identify statistically significant effects. The model reveals that all 2-way effects, i.e., Destination*Species, Destination*House, and Species*House are statistically significant (Tables C-8, C-10, and C-11, and Figures C-5, C-7, and C-8, respectively). That is, *L. fasciola* in the Nolichucky River had the greatest impact on absolute growth rate (fastest growth). The Nolichucky River, regardless of housing type, promoted the highest absolute growth rate. For mussels in the Pigeon River, those in silos had the higher absolute growth rate. *L. fasciola* grew faster than *M. conradicus* regardless of housing type, however, for *M. conradicus*, silos promoted greater absolute growth.

Relative Growth Rate

To analyze the factors that influence relative growth rate, I used a Mixed Model ANOVA, with model data shown in Table C-12 and summarized in Table C-13. The dependent variable is Relative Growth Rate and I examine the effects of Destination River, Species, and Housing (Table C-14). The full model ANOVA table is shown in Table 4-9.

Table 4-9. Full Relative Growth Rate Model ANOVA

Source	Error	DoF (numerator)	DoF (denominator)
Wp	R(Wp)	1	95
Sp	Sp*R(Wp)	1	36
SSp	SSp*Sp*R(Wp)	1	87
Wp*Sp	Sp*R(Wp)	1	36
Wp*SSp	SSp*Sp*R(Wp)	1	87
Sp*SSp	SSp*Sp*R(Wp)	1	87
Wp*Sp*SSp	SSp*Sp*R(Wp)	1	87

where Wp = Whole plot, Destination
Sp = Split plot, Species
SSp = Split Split plot, House
R = Reps

The assumptions for this model are met with normality of the model residuals (Figure C-10), no severe outliers and equality of variance (Table C-15). The model reveals that all 2-way effects, i.e., Destination*Species, Destination*House, and Species*House are statistically significant (Tables C-18, C-19, and C-20, respectively). In terms of the Destination and Species combined effect, *L. fasciola* in the Nolichucky River grew at the highest relative growth rate. For the combined

Destination and Housing effect, the Nolichucky regardless of housing and the Pigeon River mussels in cages performed best. For the combined Species and Housing effect, the *L. fasciola* in cages performed best, then *L. fasciola* and *M. conradicus* in silos and, worst, *M. conradicus* in cages.

I also developed 2 mixed model ANOVA for Relative Growth Rate for the individual species. The ANOVA table for the species-specific models is shown in Table 4-10. For *L. fasciola*, the model assumptions are met (Table C-21 and Figure C-11).

Table 4-10. Species-Specific Relative Growth Rate Model ANOVA

Source	**Error**	***L. fasciola***		***M. conradicus***	
		Num DoF	**Den DoF**	**Num DoF**	**Den DoF**
Wp	R(Wp)	1	79	1	33
Sp	Sp*R(Wp)	1	65	1	17
Wp*Sp	Sp*R(Wp)	1	65	1	17

where Wp = Whole plot, Destination
Sp = Split plot, House

The effects on *L. fasciola* Relative Growth Rate are dominated by the destination river (Tables C-22, C-23, and Figure C-12), such that the Nolichucky River provides more growth. The combined effect of Destination*House (Table C-22) is significant, in that mussels in cages in the Nolichucky had the higher growth, then those in silos in the Nolichucky.

For *M. conradicus*, the model assumptions are met (Tables C-25 and C-26, and Figure C-13). While the Destination River is not statistically significant to the Relative

Growth Rate of *M. conradicus*, the effects are dominated by the Housing (Table C-14 and Figure C-29) and the Destination (Table C-28) in which the house is located is statistically significant. They are dependent upon one another (Table C-27 and C-30). Overall, mussels in Silos grew fastest, while Silos in the Nolichucky promoted the greatest growth.

4.6 Water Quality

I conducted point water sampling for chlorophyll and provide those results below. The average Chlorophyll-A concentrations at the Pigeon River site on May 6, 2014 and the Nolichucky River site on May 15, 2014 were 12.3 μg/L and 18.5 μg/L, respectively.

Average and peak monthly water discharge rates (m^3/sec) for the Clinch, Pigeon and Nolichucky Rivers (Figures 3-19 and 3-20) indicate highly variable discharges and maximum discharges exceeding 400 m^3/sec. For each site, the maximum levels are reached in December. I examined the mean daily discharge rate for the Pigeon River site (USGS site 03461500) and the site just below Walters Dam (USGS site 03460795), for 1/1/2012 – 9/30/2014 (Figure 4-19) and found over 98% correlation over the time series (95% confidence level, p-value< 2.2e-16). Though this correlation does not imply direct causation, it does indicate that the Waterville power plant (Walters Dam) water discharge is likely the source of the Pigeon River site's high discharge rate.

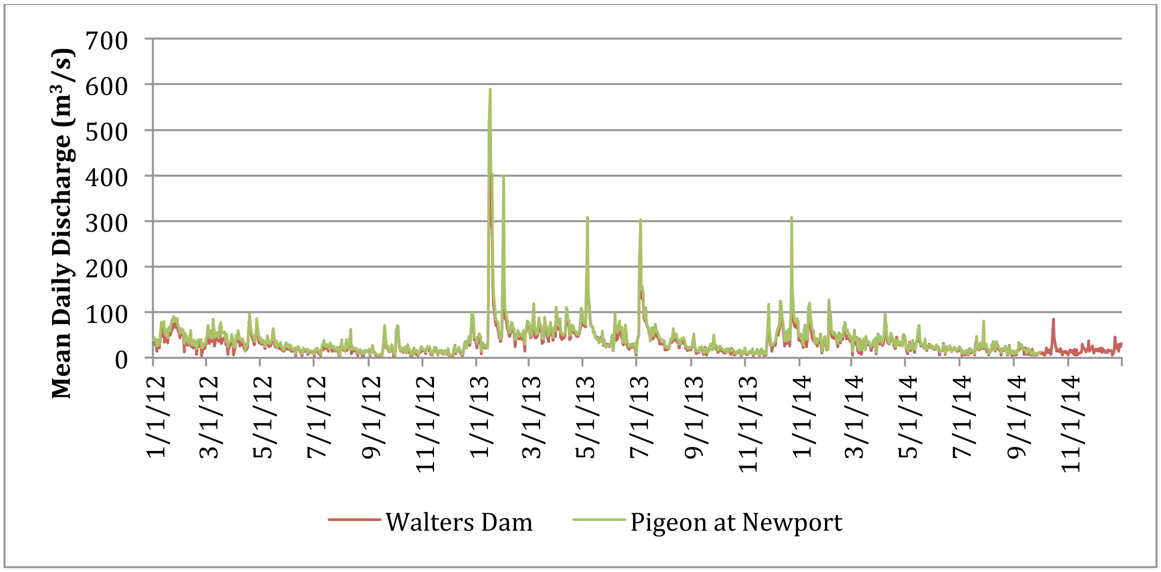

Figure 4-19. Pigeon River (USGS site 03461500) and Walters Dam (USGS site 03460795) Mean Daily Discharge (m³/s) 1/1/2012 – 9/30/2014

CHAPTER 5
DISCUSSION

The purpose of this research is to provide quantitative insights into the factors affecting freshwater mussel translocation efforts, in particular for *L. fasciola* and *M. conradicus* in the Pigeon and Nolichucky Rivers of East Tennessee. I examined the factors of the river to which the mussels were translocated (the destination site, its nutrient level, water discharge levels, sediment and siltation), the mussel enclosure or housing (cage, silo and bag released), the study time and the species themselves. Using field observations of these factors and statistical and model-based analyses, several insights were quantitatively illustrated.

One unfortunate aspect of the study is that no mussels released directly onto the substrate (bag released) were subsequently found. Hence, no statement on survival or growth of bag-released, translocated mussels can be made. A number of factors may have contributed to the inability to recover the non-housed mussels, including predation, burrowing, and water discharge volume. Though predation may have accounted for some of the unrecovered mussels, we saw no evidence of spoil piles, broken shells or unbroken and empty shells at or near the translocation sites for either species.

L. fasciola and *M. conradicus* are burrowing mussels and our inability to recover the bag-released mussels may be due in part to this behavior. We did not dig into the substrate to locate potentially burrowed mussels because doing so would disturb the habitat. Cope and Waller (1995) surveyed mussel translocation efforts and determined an overall recovery rate of 43%. For rivers in Tennessee, the recovery rate was 12.2% overall when an estimate was provided in the literature before 1995 (Cope & Waller, 1995).

The Pigeon River site (consisting of boulders, cobbles and exposed bedrock, with some fine sediments) may have prevented burrowing. The Clinch and Nolichucky Rivers have fine sediments that are more suitable for burrowing. The Nolichucky River site had the highest peak discharge - over 500 m^3/s during the study period (December, 2013). Discharge was also high (and also highest in December, 2013) in the Pigeon River and the source Clinch River, both over 400 m^3/s. Given the initial weights of the mussels under 5 g, the translocated mussels may have been washed away by high water velocities.

All translocated mussels placed in cages or silos were recovered and analyzed. The cage and silo housings are effective in protecting mussels from predators and high velocity, thus enabling their recovery. Of the recovered mussels, the survival rates were 59% and 63% for cages and silos, respectively, much higher than the survival rate for rivers in Tennessee in Cope and Waller's (1995) survey (11.4%).

The *L. fasciola* in this study were sub-adults when released in October, 2013. Hanlon and Neves (2006) note that juvenile *L. fasciola* released in June had greater survival rates than those released in September or March. Those released in September and March experienced high mortality within the first month of release. They also find that overwinter survival exhibited a size-dependent relationship. Due to the limited sample size of my interim survey, a statistical evaluation of size-dependent over-winter survival was not possible.

Comparing the survival rate for *L. fasciola* in the Pigeon River (72%), Nolichucky River (66%) and those held by AWCC (100%) shows that the AWCC-held *L. fasciola* had the highest survival rate. This is likely due to the 1) consistent availability of nutrients, 2) lack of siltation and 3) low water velocities and low velocity variability for the *L. fasciola* raised by AWCC. The survival rates for cage and silo-housed mussels were quite close. However, if we look at the condition of the housing in relation to survival, we see that those mussels in the most heavily silted (~90%

silted) houses suffered the highest mortality (81%), although those housed with 50-70% silt had the highest survival (100%). This may have occurred because of potential differences in timing of siltation of the houses, with earlier siltation resulting in a more completely silted enclosure and higher mortality. Those with the second highest level of siltation may have been able to best survive because of the availability of enough room and fine sediment for many of those mussels to partially burrow within the enclosure.

Using mixed model ANOVA to identify the most significant effects on survival of the mussels in this study, there are several findings. Time has the most significant effect on translocated mussel survival. Specifically, survival decreases with time for both species, as expected. What is unexpected is the rate at which survival decreases. It is unknown what may have caused this decline, but initial handling and translocation stresses may have played a role. In addition, I find the effect on survival of the Time and House interaction is significant. Survival decreases with Time and House. The difference occurs at the interim survey where silos supported higher survival than cages. This may be due to the Bernoulli effect in silos providing more nutrients and oxygenated water or to unidentified sampling bias at the interim survey. Contrary to my expectations, the Destination River was not statistically significant to translocated mussel survival.

Species-specific models revealed the same results as the full model, with Time being very significant to *L. fasciola* survival. The similarity of results in the full and species-specific models may be due to the similarity in survival rate for both species. Follow-on surveys of these mussels or longer-term studies of these species are recommended to determine if these results hold with additional time.

Hanlon and Neves (2006) reported juvenile *L. fasciola* growth observations (in addition to survival). Those released in June had greater growth rates than those released in September and March. Those released in September or March exhibited poor growth in the cool seasonal water conditions. The average 30 day relative growth rate for *L. fasciola* at the final survey for this study was 3 times that in the interim survey. This is likely due to slowed growth during the fall and winter seasons.

A 2004-2008 study in Clinch River in Tennessee (Jones & Neves, 2011) found *L. fasciola* maximum age and size to be 45 years and 91.3mm for males, and 24 years and 79.8mm for females. The 2014 TWRA survey (TWRA, 2014) found the length of *M. conradicus* collected in the Clinch River ranged from 25-55mm. In the Nolichucky River, *M. conradicus* length ranged from 15-45mm (not including *M. conradicus* in this study). Ages were not reported. The length of AWCC-held *L. fasciola* ranged from 15.7-24.2mm (average 20.9mm). The translocated *L. fasciola* of this study ranged in size from 19.08-58.97 (average 31.87mm), and the *M. conradicus* size ranged from 25.31-50.92mm (average 40.56mm) at the end of the study. The minimum lengths of both species are within reported normal ranges. The minimum length of the study *L. fasciola* was less than that of the AWCC-held *L. fasciola* because of shell shrinkage in some of the translocated mussels. Shrinkage is common in mussels that are stressed (Haag, 2012).

The maximum lengths of mussels in this study are smaller than the maximum lengths recorded in the wild because the translocated mussels were less than 5 years old when measured at the final survey, much younger than their maximum reported age. The maximum length of the study *L. fasciola* was greater than that of the AWCC-held *L. fasciola*. This may be due to increased nutrification from agricultural run-off. However, along with the nitrogen in agricultural run-off comes other pollutants such as pesticides and fine sediments that serve to suffocate the mussels. These pollutants and other chemical toxins decrease survival of mussels with increased exposure and concentrations (Hariharan et al. 2014).

Relative growth rate for *L. fasciola* was greater than that for *M. conradicus*. While both species exhibited shell shrinkage, *M. conradicus* suffered greater shrinkage. In particular, those mussels in heavily silted housings exhibited a negative average relative growth rate.

Using mixed model ANOVA to identify the most significant effects on relative growth rate of the mussels in this study, I find that all 2-way effects, i.e., Destination*Species, Destination*House, and Species*House, are statistically significant for both species. *L. fasciola* grew faster than *M. conradicus* and silos promoted faster growth than cages. In terms of the Destination and Species combined effect, *L. fasciola* in the Nolichucky River grew at the highest relative growth rate. For the combined Destination and Housing effect, the Nolichucky River, regardless of housing, and the Pigeon River mussels in cages performed best. For the combined Species and Housing effect, the *L. fasciola* in cages performed best, then *L. fasciola* and *M. conradicus* in silos and, worst, *M. conradicus* in cages.

The *L. fasciola*-specific growth rate model revealed that the Destination River dominates the effects on *L. fasciola* Relative Growth Rate, with the Nolichucky River promoting faster growth of *L. fasciola*. In addition, the combined effect of Destination and House is significant. That is, if the destination is the Nolichucky, Silos promote faster growth. However, in the Pigeon River, there was no significant difference in growth rates for either housing.

The *M. conradicus*-specific growth rate model revealed that the effects on relative growth rate of *M. conradicus* are dominated by *Housing*, with Silos promoting faster growth. The Destination in which the house is located is significant, where Silos in the Pigeon River promote the fastest growth. We see a difference between species with respect to Destination and/or housing. Follow-on surveys of these mussels and longer-term studies of these species are recommended to determine if these results hold with additional time.

Average monthly water discharge rates (m^3/sec) for the Clinch, Pigeon and Nolichucky Rivers indicate highly variable discharges and maximum discharges exceeding 400 m^3/sec. For each site, the maximum levels are reached in December. The mean daily discharge rate for the Pigeon River site and the site just below Walters Dam, for 1/1/2012 – 9/30/2014 have over 98% correlation. Though this correlation does not imply direct causation, it does indicate that the Waterville power plant water discharge is likely the source of the Pigeon River site's high discharge rate and a negative factor in the survival and growth of freshwater mussels.

Through this study I sought to determine the mechanism(s) that influence the outcomes of recent Tennessee freshwater mussel translocations. The ability to house the translocated mussels is important to the ability to recover and analyze the mussels. When the conditions of these enclosures become significantly silted (over 90%), however, the mussels can suffer shell shrinkage and increased mortality. One may consider more frequent surveys and release of housed mussels when their housing condition deteriorates (or rinsing the housing of sediment). At some point the housed mussels will grow to a size at which the volume of the housing limits growth and possibly, survival.

A surprising result of the multi-factor modeling is that the destination river was not a significant effect in the survival of the translocated mussels. The Nolichucky River was the sole destination with housing suffering significant siltation. One wonders whether finding some of the released mussels may have added support to or contradicted this finding. The destination river was significant only in the relative growth rate of *L. fasciola*, with the Nolichucky River promoting faster growth.

Recommendations for future research:

Several small, single-investigator freshwater mussel studies have been and continue to be conducted in Tennessee rivers. Given the paucity of funding directed toward freshwater mussel community restoration, I suggest open and timely data sharing between those investigators and with the scientific community at large. Given this collection of data, along with the associated data collection methods, a better understanding of freshwater mussel communities and restoration success factors can be discerned at lower future costs. Having this data available can also facilitate longer-term research.

I suggest future research take periodic and quantitative observations over multi-year studies. Factors should include water quality (chemical, geological, and physical characteristics); sediment specifics; other mussels, host fish, and predators in the community; mussel biology and nutrient availability.

Implications for conservation efforts:

The results of this study indicate that both *L. fasciola* and *M. conradicus* can be successfully translocated to the Pigeon River, if 1) the mussels were translocated where the Pigeon River has less boulder, cobble and exposed bedrock in favor of more coarse and fine gravel and sand, 2) the Pigeon River had lower peak and average discharge rates, particularly at critical times in the mussel lifecycle, 3) some translocations occurred in the spring-early summer, and 4) the translocated mussels are initially housed in cages or silos. The silo and cage enclosures were helpful in recovering mussels for analysis. None of the non-housed mussels were recovered, primarily due to high water volumes and velocities in the first third of the study. The housed mussels were protected from these issues. However, if mussels are initially translocated in the heavy silos and rock-wedged cages, at some point those mussels will be released. Though the mussels in this study were pre-adult and were not sexually mature, the high water velocity in the Pigeon River will likely reduce the time male mussel sperm are spatially accessible to local female mussels. This reduces the opportunity for recruitment. Due to significant mortality in the first third of this study, some studies should start in the spring-early summer rather than in September/October to help translocated mussels survive their first over-winter by having some growth and habitat acclimation underway. In addition, siltation of the enclosures and mussel growth should be monitored to ensure the volume available to the mussels is sufficient.

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APPENDICES

APPENDIX A: Raw Data

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013

TagNum	Species	Length (mm)	Weight (g)
0	*L. fasciola*	26.7	2
1	*L. fasciola*	27.93	3
2	*L. fasciola*	28.71	3
3	*L. fasciola*	19.93	1
4	*L. fasciola*	23.95	2
5	*L. fasciola*	24.6	2
6	*L. fasciola*	28.32	2
7	*L. fasciola*	30.08	4
8	*L. fasciola*	24.76	2
9	*L. fasciola*	24.41	2
10	*L. fasciola*	19.98	1
11	*L. fasciola*	26.5	3
12	*L. fasciola*	21.87	2
13	*L. fasciola*	21.09	1
14	*L. fasciola*	30.18	4
15	*L. fasciola*	19.72	1
16	*L. fasciola*	25.87	2
17	*M. conradicus*	24.28	2
18	*L. fasciola*	25.35	2
19	*L. fasciola*	20.94	1
20	*L. fasciola*	26.27	2
21	*L. fasciola*	22.38	2
22	*L. fasciola*	24.59	2
23	*L. fasciola*	24.57	2
24	*L. fasciola*	24.03	2
25	*L. fasciola*	24.37	2
26	*L. fasciola*	27.09	2
27	*L. fasciola*	21.93	2
28	*L. fasciola*	19.21	0
29	*L. fasciola*	17.93	0
31	*L. fasciola*	22.2	0
32	*L. fasciola*	26.74	3
33	*L. fasciola*	21.25	2
34	*L. fasciola*	24.95	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
35	*L. fasciola*	22.78	1
36	*L. fasciola*	21.34	1
37	*L. fasciola*	18.03	0
38	*L. fasciola*	25.57	2
39	*L. fasciola*	23.88	2
40	*M. conradicus*	28.52	3
41	*L. fasciola*	22.18	2
42	*L. fasciola*	21.65	1
43	*L. fasciola*	28.41	3
44	*L. fasciola*	20.92	1
45	*L. fasciola*	20.79	1
46	*L. fasciola*	23.58	2
47	*L. fasciola*	28.27	3
48	*L. fasciola*	30.83	4
49	*L. fasciola*	27.27	2
50	*L. fasciola*	19.33	1
51	*L. fasciola*	24.69	2
52	*L. fasciola*	23.28	2
53	*L. fasciola*	20.52	1
54	*L. fasciola*	29.98	4
55	*L. fasciola*	30.1	3
56	*L. fasciola*	25.08	2
57	*L. fasciola*	26.32	2
58	*L. fasciola*	24.05	2
59	*L. fasciola*	20.68	2
60	*L. fasciola*	23.67	2
61	*L. fasciola*	19.62	1
62	*L. fasciola*	23.07	2
63	*L. fasciola*	24.93	2
64	*L. fasciola*	22.9	0
65	*L. fasciola*	26.17	2
66	*L. fasciola*	20.75	0
67	*L. fasciola*	26.35	2
68	*L. fasciola*	19.88	1
69	*L. fasciola*	26	2
70	*L. fasciola*	27.61	3
71	*L. fasciola*	21.63	1
72	*L. fasciola*	19.58	1

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
73	*L. fasciola*	19.11	1
74	*L. fasciola*	27.58	2
75	*L. fasciola*	20.97	1
76	*L. fasciola*	17.68	1
77	*L. fasciola*	27.15	3
78	*L. fasciola*	21.21	2
79	*L. fasciola*	22.85	2
80	*L. fasciola*	24.32	2
81	*L. fasciola*	28.05	3
82	*L. fasciola*	24.44	2
83	*L. fasciola*	25.3	2
84	*L. fasciola*	25.57	2
85	*L. fasciola*	25.75	2
86	*L. fasciola*	30.04	3
87	*L. fasciola*	20.44	1
88	*M. conradicus*	26.46	3
89	*L. fasciola*	19.2	0
90	*L. fasciola*	26.5	2
91	*L. fasciola*	28.51	3
92	*L. fasciola*	23.41	2
93	*L. fasciola*	27.52	3
94	*L. fasciola*	22.65	2
95	*L. fasciola*	26.06	2
96	*L. fasciola*	26.48	2
97	*L. fasciola*	22.73	1
98	*L. fasciola*	24.03	1
99	*L. fasciola*	26.49	2
100	*L. fasciola*	19.6	1
101	*L. fasciola*	29.19	4
102	*L. fasciola*	23.3	2
103	*L. fasciola*	21.88	1
104	*L. fasciola*	20.1	1
105	*L. fasciola*	26.67	3
106	*L. fasciola*	16.82	0
107	*L. fasciola*	25.92	2
108	*L. fasciola*	26	2
110	*L. fasciola*	23.71	2
111	*L. fasciola*	26.2	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
112	*L. fasciola*	29.06	3
113	*L. fasciola*	29.11	3
114	*L. fasciola*	25.88	3
115	*L. fasciola*	23.5	2
116	*L. fasciola*	21.14	2
117	*L. fasciola*	20.34	1
118	*L. fasciola*	23.71	2
119	*L. fasciola*	24.38	2
120	*L. fasciola*	19.77	0
121	*M. conradicus*	27	3
122	*L. fasciola*	20.5	0
123	*M. conradicus*	20.92	1
124	*L. fasciola*	25.14	3
125	*L. fasciola*	23.67	2
126	*L. fasciola*	27.36	3
127	*L. fasciola*	28.72	3
128	*L. fasciola*	25.74	2
129	*L. fasciola*	20.07	1
130	*L. fasciola*	20.86	1
131	*L. fasciola*	19.11	0
132	*L. fasciola*	21.42	1
133	*M. conradicus*	23.78	2
134	*L. fasciola*	26.12	2
135	*L. fasciola*	21.58	1
136	*L. fasciola*	20.57	1
137	*L. fasciola*	27.24	2
138	*L. fasciola*	25.94	2
139	*L. fasciola*	25.94	2
140	*L. fasciola*	20.32	0
141	*L. fasciola*	23.89	1
142	*L. fasciola*	26.48	3
143	*L. fasciola*	21.86	2
144	*L. fasciola*	27.36	3
145	*L. fasciola*	19.61	1
146	*L. fasciola*	26.06	2
147	*L. fasciola*	22.46	2
148	*L. fasciola*	23.14	1
149	*L. fasciola*	26.72	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
150	*L. fasciola*	28.88	4
151	*L. fasciola*	23.54	2
152	*L. fasciola*	23.41	2
153	*L. fasciola*	21.39	1
154	*L. fasciola*	24.01	2
155	*L. fasciola*	24.76	2
156	*L. fasciola*	24.41	3
157	*L. fasciola*	23.3	2
158	*L. fasciola*	21.1	1
159	*L. fasciola*	21.34	2
160	*L. fasciola*	19.97	1
161	*L. fasciola*	28.69	3
162	*L. fasciola*	24.56	2
163	*L. fasciola*	27.29	2
164	*L. fasciola*	21.34	1
165	*L. fasciola*	20.52	1
166	*L. fasciola*	24.2	3
167	*L. fasciola*	23.63	2
168	*L. fasciola*	25.47	2
169	*L. fasciola*	19.5	1
170	*L. fasciola*	23.38	2
171	*L. fasciola*	23.99	2
172	*L. fasciola*	27.86	3
173	*L. fasciola*	25.99	3
174	*L. fasciola*	29.2	3
175	*L. fasciola*	23.58	2
176	*L. fasciola*	18.4	0
177	*L. fasciola*	26.76	2
178	*L. fasciola*	28.6	3
179	*L. fasciola*	21.75	2
180	*L. fasciola*	19.6	1
181	*L. fasciola*	27.38	3
182	*L. fasciola*	23.82	3
183	*L. fasciola*	27.33	4
184	*L. fasciola*	26.49	4
185	*L. fasciola*	21.9	0
186	*L. fasciola*	28.95	3
187	*L. fasciola*	22.44	1

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
188	*M. conradicus*	24.78	1
189	*L. fasciola*	21.42	0
190	*L. fasciola*	27.19	2
192	*L. fasciola*	28.97	2
193	*L. fasciola*	23.11	1
194	*L. fasciola*	25.88	2
195	*L. fasciola*	23.83	1
196	*L. fasciola*	23.01	0
197	*L. fasciola*	18.43	0
198	*L. fasciola*	20.6	1
199	*L. fasciola*	27.18	2
200	*M. conradicus*	30.24	4
201	*M. conradicus*	23.75	2
202	*L. fasciola*	23.88	2
203	*L. fasciola*	26.97	2
204	*L. fasciola*	23.44	2
205	*L. fasciola*	29.3	3
206	*L. fasciola*	28.39	3
207	*L. fasciola*	22.67	2
208	*M. conradicus*	22.03	2
209	*L. fasciola*	26.28	2
210	*L. fasciola*	23.95	2
211	*L. fasciola*	25.81	2
212	*L. fasciola*	16.65	0
213	*L. fasciola*	21.05	1
214	*L. fasciola*	19.08	1
215	*L. fasciola*	18.83	1
216	*L. fasciola*	26.03	2
217	*L. fasciola*	21.47	1
218	*L. fasciola*	18.38	0
219	*L. fasciola*	24.79	2
220	*L. fasciola*	15.55	0
221	*L. fasciola*	24.47	2
222	*L. fasciola*	22	1
223	*L. fasciola*	23.44	1
224	*M. conradicus*	24.43	2
225	*L. fasciola*	25.81	3
226	*L. fasciola*	22.55	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
227	*L. fasciola*	21.71	1
228	*L. fasciola*	21.95	2
229	*L. fasciola*	20.13	0
230	*L. fasciola*	18.85	0
231	*L. fasciola*	21.66	0
232	*L. fasciola*	24.2	2
233	*L. fasciola*	30.99	4
234	*L. fasciola*	18.9	1
235	*L. fasciola*	19.96	1
236	*L. fasciola*	19.77	1
237	*L. fasciola*	20.31	1
238	*L. fasciola*	23.8	2
239	*L. fasciola*	21.01	1
240	*L. fasciola*	24.03	2
241	*L. fasciola*	21.6	1
242	*L. fasciola*	25.05	2
243	*L. fasciola*	21.58	1
244	*L. fasciola*	24.41	2
245	*L. fasciola*	23.47	1
246	*L. fasciola*	17.58	0
247	*L. fasciola*	26.16	2
248	*L. fasciola*	19.08	1
249	*L. fasciola*	26.15	2
250	*L. fasciola*	27.17	3
251	*L. fasciola*	26.26	2
252	*L. fasciola*	28.24	3
253	*L. fasciola*	27.95	3
254	*L. fasciola*	22.98	2
255	*L. fasciola*	21.26	1
256	*L. fasciola*	21.98	2
257	*L. fasciola*	20.08	1
258	*L. fasciola*	21.35	1
259	*L. fasciola*	25.82	2
260	*L. fasciola*	26.15	2
261	*M. conradicus*	19.84	1
262	*L. fasciola*	17.86	0
263	*L. fasciola*	20.56	1
264	*L. fasciola*	21.83	1

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
265	*L. fasciola*	26.09	2
266	*L. fasciola*	21.54	1
267	*L. fasciola*	21.14	2
268	*L. fasciola*	26.86	2
269	*L. fasciola*	27.39	3
270	*L. fasciola*	23.41	2
271	*L. fasciola*	25.29	2
272	*L. fasciola*	26.53	2
273	*L. fasciola*	20.25	1
274	*L. fasciola*	23.49	2
275	*L. fasciola*	20.64	0
276	*L. fasciola*	28.04	2
277	*L. fasciola*	27.51	1
278	*L. fasciola*	24.17	2
279	*L. fasciola*	27	2
280	*L. fasciola*	26.32	2
281	*L. fasciola*	24.57	2
282	*L. fasciola*	24.54	2
283	*L. fasciola*	23.59	2
284	*L. fasciola*	22.87	1
285	*L. fasciola*	20.07	1
286	*L. fasciola*	19.69	1
287	*L. fasciola*	19.57	0
288	*L. fasciola*	21.67	2
289	*L. fasciola*	18.94	1
290	*L. fasciola*	20.25	1
291	*L. fasciola*	20.17	1
292	*L. fasciola*	26.27	2
293	*L. fasciola*	20.31	0
294	*L. fasciola*	19.99	1
295	*L. fasciola*	26.13	2
296	*L. fasciola*	18.07	1
297	*L. fasciola*	18.92	1
298	*L. fasciola*	23.37	1
299	*L. fasciola*	24.16	2
300	*L. fasciola*	19.2	1
301	*L. fasciola*	20.93	1
302	*L. fasciola*	18.96	0

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
303	*L. fasciola*	20.52	0
304	*L. fasciola*	26.13	2
305	*L. fasciola*	25.38	1
306	*L. fasciola*	19.55	0
307	*L. fasciola*	26.88	1
308	*L. fasciola*	27.06	2
309	*L. fasciola*	21.17	1
310	*L. fasciola*	18.51	1
311	*L. fasciola*	22.93	1
312	*L. fasciola*	19.54	0
313	*L. fasciola*	26.5	2
314	*L. fasciola*	19.17	0
315	*L. fasciola*	27.01	2
316	*L. fasciola*	22.9	0
317	*L. fasciola*	19.33	0
318	*L. fasciola*	23.35	1
319	*L. fasciola*	19.06	1
320	*L. fasciola*	20.82	1
321	*L. fasciola*	27	2
322	*L. fasciola*	29.45	2
323	*L. fasciola*	23.39	1
324	*L. fasciola*	21.96	0
325	*L. fasciola*	17.26	0
326	*L. fasciola*	23.61	1
327	*L. fasciola*	28.76	2
328	*L. fasciola*	19.7	0
329	*L. fasciola*	18.9	0
330	*L. fasciola*	16.62	0
331	*L. fasciola*	19.66	0
332	*L. fasciola*	21.32	1
333	*L. fasciola*	19.67	0
334	*L. fasciola*	18.42	0
335	*L. fasciola*	20.55	1
336	*L. fasciola*	23.03	2
337	*L. fasciola*	28.01	2
338	*L. fasciola*	29.47	3
339	*L. fasciola*	25.67	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
340	*M. conradicus*	24.62	2
341	*L. fasciola*	26.06	2
342	*M. conradicus*	26.23	2
343	*L. fasciola*	22.26	1
344	*L. fasciola*	21.06	2
345	*M. conradicus*	21.94	0
346	*L. fasciola*	21.92	2
347	*L. fasciola*	25.74	1
348	*L. fasciola*	21.01	1
349	*L. fasciola*	19.5	0
350	*L. fasciola*	21.42	2
351	*L. fasciola*	25.69	2
352	*L. fasciola*	24.61	2
353	*L. fasciola*	21.93	1
354	*M. conradicus*	27.68	3
355	*L. fasciola*	20.88	1
356	*L. fasciola*	27.09	3
357	*L. fasciola*	22.92	0
358	*L. fasciola*	25.68	2
359	*L. fasciola*	19.07	0
360	*L. fasciola*	21.75	2
361	*L. fasciola*	25	2
362	*L. fasciola*	25.24	2
363	*L. fasciola*	23.54	1
364	*L. fasciola*	22.87	2
365	*L. fasciola*	25.36	2
366	*L. fasciola*	21.61	1
367	*L. fasciola*	24.94	2
368	*L. fasciola*	29.24	3
369	*L. fasciola*	20.66	1
370	*L. fasciola*	23.67	2
371	*L. fasciola*	28.68	3
372	*L. fasciola*	17.09	0
373	*L. fasciola*	24.09	1
374	*L. fasciola*	22.72	2
375	*L. fasciola*	20.44	0
376	*L. fasciola*	20.78	0

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
377	*L. fasciola*	23.9	1
378	*L. fasciola*	21.9	1
379	*L. fasciola*	23.24	1
380	*L. fasciola*	19.84	1
381	*L. fasciola*	23.67	0
382	*L. fasciola*	23.05	2
383	*L. fasciola*	24.13	0
384	*L. fasciola*	26.35	3
385	*L. fasciola*	20.46	1
386	*L. fasciola*	19.82	1
387	*L. fasciola*	21.69	1
388	*M. conradicus*	26.89	3
389	*L. fasciola*	19.88	0
390	*L. fasciola*	23.2	2
391	*L. fasciola*	19.03	0
392	*L. fasciola*	20.55	0
393	*L. fasciola*	18.26	0
394	*L. fasciola*	20.41	0
395	*L. fasciola*	19.63	1
396	*M. conradicus*	52.03	14
397	*M. conradicus*	44.09	8
398	*M. conradicus*	46.04	10
399	*M. conradicus*	45.07	7
400	*M. conradicus*	46.54	8
401	*M. conradicus*	26.82	9
402	*M. conradicus*	45.36	8
403	*M. conradicus*	42.05	5
404	*M. conradicus*	36.69	3
405	*M. conradicus*	44.16	6
406	*M. conradicus*	44.61	7
407	*M. conradicus*	32.98	2
408	*M. conradicus*	36.73	3
409	*M. conradicus*	30.93	2
410	*M. conradicus*	43	5
411	*M. conradicus*	30	2
412	*M. conradicus*	29.08	1
413	*M. conradicus*	45.74	8
414	*M. conradicus*	41.52	4

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
415	*M. conradicus*	31.71	2
416	*M. conradicus*	34.86	3
417	*M. conradicus*	39.92	4
418	*M. conradicus*	46.73	6
419	*M. conradicus*	32.31	2
420	*M. conradicus*	29.38	8
421	*M. conradicus*	49.47	8
422	*M. conradicus*	41.17	4
423	*M. conradicus*	41.38	5
424	*M. conradicus*	34.54	3
425	*M. conradicus*	33.05	3
426	*M. conradicus*	33.27	2
428	*M. conradicus*	40.47	4
429	*M. conradicus*	42.86	9
430	*M. conradicus*	44.57	6
431	*M. conradicus*	38.8	4
432	*M. conradicus*	39.99	4
433	*M. conradicus*	32.02	2
434	*M. conradicus*	40.36	4
435	*M. conradicus*	29.47	2
436	*M. conradicus*	26.96	1
437	*M. conradicus*	37.19	3
438	*M. conradicus*	49.54	7
439	*M. conradicus*	32.58	3
440	*M. conradicus*	43.53	6
441	*M. conradicus*	29.88	4
442	*M. conradicus*	43.18	10
443	*M. conradicus*	40.4	7
444	*M. conradicus*	34.55	4
445	*M. conradicus*	29.51	2
446	*M. conradicus*	34.06	2
447	*M. conradicus*	34.94	5
448	*M. conradicus*	46.06	8
449	*M. conradicus*	40.44	6
450	*M. conradicus*	47.78	13
451	*M. conradicus*	39.18	8
452	*M. conradicus*	37.47	4
453	*M. conradicus*	30.88	4

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
454	*M. conradicus*	34.36	5
455	*M. conradicus*	35.81	4
456	*M. conradicus*	26.33	2
457	*M. conradicus*	38.6	4
458	*M. conradicus*	33.05	4
459	*M. conradicus*	42.93	6
460	*M. conradicus*	39.03	7
461	*M. conradicus*	41.68	7
462	*M. conradicus*	35.45	4
463	*M. conradicus*	39.94	6
464	*M. conradicus*	44.61	9
465	*M. conradicus*	38.33	6
466	*M. conradicus*	31.5	3
467	*M. conradicus*	25.03	2
468	*M. conradicus*	44.96	10
469	*M. conradicus*	39.63	6
470	*M. conradicus*	36.28	5
471	*M. conradicus*	46.57	9
472	*M. conradicus*	23.8	1
473	*M. conradicus*	29.74	3
474	*M. conradicus*	30.95	3
475	*M. conradicus*	29.25	3
476	*M. conradicus*	22.77	2
477	*M. conradicus*	26.01	2
478	*M. conradicus*	25.9	2
479	*M. conradicus*	25.21	2
480	*M. conradicus*	24.52	2
481	*M. conradicus*	20.95	1
482	*M. conradicus*	22.88	1
483	*M. conradicus*	31.93	3
484	*M. conradicus*	35.36	4
485	*M. conradicus*	40.46	6
486	*M. conradicus*	23.5	1
487	*M. conradicus*	29.76	3
488	*M. conradicus*	23.38	2
489	*M. conradicus*	20.57	1
490	*M. conradicus*	37.67	5
491	*M. conradicus*	39.28	6

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
492	*M. conradicus*	46.5	9
493	*M. conradicus*	33.9	2
494	*M. conradicus*	46.39	10
495	*M. conradicus*	49.66	12
496	*M. conradicus*	35.05	6
497	*M. conradicus*	28.53	3
498	*M. conradicus*	46.08	10
499	*M. conradicus*	34.7	4
500	*M. conradicus*	39.62	6
501	*M. conradicus*	41.62	6
503	*M. conradicus*	45.62	8
504	*M. conradicus*	29.63	4
505	*M. conradicus*	46.15	14
506	*M. conradicus*	32	3
507	*M. conradicus*	40.45	7
508	*M. conradicus*	37.64	5
509	*M. conradicus*	34.4	4
510	*M. conradicus*	34.98	5
511	*M. conradicus*	42.91	8
512	*M. conradicus*	42.29	7
513	*M. conradicus*	32.49	3
514	*M. conradicus*	29.98	2
515	*M. conradicus*	45.92	8
516	*M. conradicus*	49.14	15
517	*M. conradicus*	44.55	12
518	*M. conradicus*	36.09	4
519	*M. conradicus*	36.46	5
520	*M. conradicus*	40.68	7
521	*M. conradicus*	39.77	5
522	*M. conradicus*	47.56	10
523	*M. conradicus*	40.92	6
524	*M. conradicus*	39.47	6
525	*M. conradicus*	33.31	4
526	*M. conradicus*	50.7	16
527	*M. conradicus*	46.49	10
528	*M. conradicus*	48.45	13
529	*M. conradicus*	44.23	7
530	*M. conradicus*	43.66	10

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
531	*M. conradicus*	39.13	5
532	*M. conradicus*	29.57	3
533	*M. conradicus*	35.07	4
534	*M. conradicus*	30.83	3
535	*M. conradicus*	37.21	4
536	*M. conradicus*	41.99	7
537	*M. conradicus*	37.03	4
538	*M. conradicus*	23.99	1
539	*M. conradicus*	28.08	2
540	*M. conradicus*	40.71	6
541	*M. conradicus*	38.81	6
542	*M. conradicus*	33.99	5
543	*M. conradicus*	28.89	2
544	*M. conradicus*	26.64	2
545	*M. conradicus*	30.29	2
546	*M. conradicus*	31.5	3
547	*M. conradicus*	48.99	11
548	*M. conradicus*	46.8	11
549	*M. conradicus*	33.67	4
550	*M. conradicus*	49.54	14
551	*M. conradicus*	35.22	4
552	*M. conradicus*	36.44	5
553	*M. conradicus*	45.84	12
554	*M. conradicus*	37.34	7
555	*M. conradicus*	49.77	13
556	*M. conradicus*	44.38	11
557	*M. conradicus*	50.17	13
558	*M. conradicus*	39.18	6
559	*M. conradicus*	33.91	3
560	*M. conradicus*	45.52	6
561	*M. conradicus*	37.76	6
562	*M. conradicus*	45.25	5
563	*M. conradicus*	24.01	1
564	*M. conradicus*	41.75	6
565	*M. conradicus*	33.35	3
566	*M. conradicus*	45.41	11
567	*M. conradicus*	46.69	11
568	*M. conradicus*	44.23	8

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
569	*M. conradicus*	31.52	3
570	*M. conradicus*	28.66	2
571	*M. conradicus*	38.09	5
572	*M. conradicus*	21.96	0
573	*M. conradicus*	40.92	7
574	*M. conradicus*	45.44	10
575	*M. conradicus*	42.67	7
576	*M. conradicus*	41.38	7
577	*M. conradicus*	38.61	6
578	*M. conradicus*	35.99	4
579	*M. conradicus*	40.38	6
580	*M. conradicus*	39.81	6
581	*M. conradicus*	45.22	9
582	*M. conradicus*	32.47	3
583	*M. conradicus*	26.94	2
584	*M. conradicus*	33.91	4
585	*M. conradicus*	46.01	4
586	*M. conradicus*	32.27	4
587	*M. conradicus*	29.22	3
588	*M. conradicus*	41.11	8
589	*M. conradicus*	39.03	8
590	*M. conradicus*	29.39	2
591	*M. conradicus*	33.86	4
592	*M. conradicus*	50.28	13
593	*M. conradicus*	41.92	6
594	*M. conradicus*	34.98	4
595	*M. conradicus*	40.01	6
596	*M. conradicus*	29.38	2
597	*M. conradicus*	40.14	7
598	*M. conradicus*	31.16	3
599	*M. conradicus*	29.31	2
600	*M. conradicus*	39.51	6
601	*M. conradicus*	46.41	10
602	*M. conradicus*	30.41	2
604	*M. conradicus*	31.46	2
605	*M. conradicus*	37.44	6

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
606	*M. conradicus*	29.6	2
607	*M. conradicus*	39.31	5
608	*M. conradicus*	32.72	4
609	*M. conradicus*	27.5	2
610	*M. conradicus*	29.51	3
611	*M. conradicus*	48.98	13
612	*M. conradicus*	51.22	16
613	*M. conradicus*	44.54	9
614	*M. conradicus*	38.71	5
615	*M. conradicus*	32.86	4
616	*M. conradicus*	37.23	5
617	*M. conradicus*	50.2	10
618	*M. conradicus*	36.81	6
619	*M. conradicus*	31.78	3
620	*M. conradicus*	43.76	8
621	*M. conradicus*	46.7	12
622	*M. conradicus*	42.73	6
623	*M. conradicus*	37.73	5
624	*M. conradicus*	46.1	10
625	*M. conradicus*	34.49	4
626	*M. conradicus*	38.81	7
627	*M. conradicus*	47.02	8
628	*M. conradicus*	53.54	14
629	*M. conradicus*	50	14
630	*M. conradicus*	39.66	7
631	*M. conradicus*	32.08	3
632	*M. conradicus*	38.22	6
633	*M. conradicus*	36.9	5
634	*M. conradicus*	44.55	10
635	*M. conradicus*	49.64	14
636	*M. conradicus*	44.39	10
637	*M. conradicus*	36.67	5
638	*M. conradicus*	46.82	11
639	*M. conradicus*	41.39	6
640	*M. conradicus*	43.88	8
641	*M. conradicus*	32.46	3
643	*M. conradicus*	31.48	4
644	*M. conradicus*	37.9	4

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
645	*M. conradicus*	43.77	9
646	*M. conradicus*	41.62	8
647	*M. conradicus*	41.05	7
648	*M. conradicus*	49.45	11
649	*M. conradicus*	46.77	8
650	*M. conradicus*	34.53	4
651	*M. conradicus*	40.15	6
652	*M. conradicus*	33	3
653	*M. conradicus*	40.28	6
654	*M. conradicus*	32.7	3
655	*M. conradicus*	31.27	2
656	*M. conradicus*	47.68	12
657	*M. conradicus*	38.9	6
658	*M. conradicus*	41.61	9
659	*M. conradicus*	32.92	3
660	*M. conradicus*	36.42	4
661	*M. conradicus*	45.14	7
662	*M. conradicus*	37.55	6
663	*M. conradicus*	43.77	7
664	*M. conradicus*	45.92	9
665	*M. conradicus*	46.65	12
666	*M. conradicus*	42.71	7
667	*M. conradicus*	50.94	12
668	*M. conradicus*	37.06	4
669	*M. conradicus*	33.16	3
670	*M. conradicus*	39.42	6
671	*M. conradicus*	43.75	8
672	*M. conradicus*	29.96	2
673	*M. conradicus*	35.47	5
674	*M. conradicus*	28.88	3
675	*M. conradicus*	28.39	2
676	*M. conradicus*	34	4
677	*M. conradicus*	39.55	6
678	*M. conradicus*	38.05	7
679	*M. conradicus*	30.24	3
680	*M. conradicus*	41.68	7
681	*M. conradicus*	44.17	8
682	*M. conradicus*	29.22	2

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
683	*M. conradicus*	42.02	8
684	*M. conradicus*	28	3
685	*M. conradicus*	39.87	7
686	*M. conradicus*	35.94	4
687	*M. conradicus*	26.72	0
688	*M. conradicus*	36.8	6
689	*M. conradicus*	25.97	2
690	*M. conradicus*	29.36	2
691	*M. conradicus*	30.05	3
692	*M. conradicus*	44.16	8
693	*M. conradicus*	36.96	4
694	*M. conradicus*	32.59	3
695	*M. conradicus*	38.5	6
696	*M. conradicus*	32.02	3
697	*M. conradicus*	33.46	4
698	*M. conradicus*	42.59	9
699	*M. conradicus*	47.48	10
700	*M. conradicus*	38.76	5
701	*M. conradicus*	35	4
702	*M. conradicus*	30.47	3
703	*M. conradicus*	41.54	8
704	*M. conradicus*	45.52	10
705	*M. conradicus*	36.62	4
706	*M. conradicus*	34.02	4
707	*M. conradicus*	25.12	0
708	*M. conradicus*	42.87	8
709	*M. conradicus*	41.42	6
710	*M. conradicus*	45.9	13
711	*M. conradicus*	35.77	4
712	*M. conradicus*	51.05	14
713	*M. conradicus*	40.63	8
714	*M. conradicus*	44.83	11
715	*M. conradicus*	34.43	4
716	*M. conradicus*	38.14	5
717	*M. conradicus*	29.24	3
718	*M. conradicus*	45.06	11
719	*M. conradicus*	47.45	10
720	*M. conradicus*	36.11	5

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
721	*M. conradicus*	36.78	4
722	*M. conradicus*	45.2	10
723	*M. conradicus*	43.91	8
724	*M. conradicus*	47.35	11
725	*M. conradicus*	24.52	2
726	*M. conradicus*	44.24	9
727	*M. conradicus*	35.44	5
728	*M. conradicus*	36.51	6
729	*M. conradicus*	32.94	4
730	*M. conradicus*	38.92	7
731	*M. conradicus*	39.73	7
732	*M. conradicus*	41.78	7
733	*M. conradicus*	36.18	5
734	*M. conradicus*	37.45	6
735	*M. conradicus*	28.59	2
736	*M. conradicus*	42.75	7
737	*M. conradicus*	33.75	4
738	*M. conradicus*	44.36	10
739	*M. conradicus*	37.99	4
740	*M. conradicus*	48.94	13
741	*M. conradicus*	40.78	8
742	*M. conradicus*	26.73	2
743	*M. conradicus*	46.18	10
744	*M. conradicus*	42.51	7
745	*M. conradicus*	32.92	3
746	*M. conradicus*	36.58	6
747	*M. conradicus*	24.74	2
748	*M. conradicus*	37.5	5
749	*M. conradicus*	34.1	3
750	*M. conradicus*	29.99	3
751	*M. conradicus*	27.67	2
752	*M. conradicus*	38.64	6
753	*M. conradicus*	31.29	4
754	*M. conradicus*	47.04	11
755	*M. conradicus*	44.7	10
756	*L. fasciola*	23.29	2
757	*M. conradicus*	40.13	4
758	*M. conradicus*	28.95	3

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
759	*M. conradicus*	38.59	5
760	*L. fasciola*	13.11	0
761	*L. fasciola*	17.11	1
762	*L. fasciola*	22.74	2
763	*L. fasciola*	16.17	0
764	*L. fasciola*	19.25	1
765	*L. fasciola*	16.11	0
766	*L. fasciola*	17.26	0
767	*L. fasciola*	13.4	0
768	*L. fasciola*	22.44	2
769	*L. fasciola*	24.47	2
770	*L. fasciola*	20.36	1
771	*L. fasciola*	21.75	1
772	*L. fasciola*	21.04	0
773	*L. fasciola*	18.56	0
774	*L. fasciola*	23.85	2
775	*L. fasciola*	25.34	2
776	*L. fasciola*	22.99	2
777	*L. fasciola*	24.43	2
778	*L. fasciola*	19.45	1
779	*L. fasciola*	20.99	1
780	*L. fasciola*	26	2
781	*L. fasciola*	23.12	2
782	*L. fasciola*	20.65	0
783	*L. fasciola*	19.73	1
784	*L. fasciola*	25.96	2
785	*L. fasciola*	24.37	3
786	*L. fasciola*	22.23	3
787	*L. fasciola*	25.36	2
788	*L. fasciola*	27.67	3
789	*L. fasciola*	21.28	1
790	*L. fasciola*	17.74	0
791	*L. fasciola*	18.56	0
792	*L. fasciola*	20.91	1
793	*L. fasciola*	23.4	1
794	*L. fasciola*	22.26	0
795	*L. fasciola*	21.21	1
796	*L. fasciola*	22.37	1

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
797	*L. fasciola*	24.06	2
798	*L. fasciola*	21.25	1
799	*L. fasciola*	21.42	2
800	*L. fasciola*	23.23	2
801	*L. fasciola*	23.44	2
802	*L. fasciola*	24.65	3
803	*L. fasciola*	17.82	1
804	*L. fasciola*	20.39	1
805	*L. fasciola*	13.27	0
806	*L. fasciola*	14.83	0
807	*L. fasciola*	17.49	0
808	*L. fasciola*	16.95	0
809	*L. fasciola*	20.01	2
810	*L. fasciola*	27.86	2
811	*L. fasciola*	18.7	0
812	*L. fasciola*	17.33	0
813	*L. fasciola*	20.96	0
814	*L. fasciola*	19.43	0
815	*L. fasciola*	21.52	0
816	*L. fasciola*	16.89	1
817	*L. fasciola*	18.18	0
818	*L. fasciola*	21.34	0
819	*L. fasciola*	18.9	0
820	*L. fasciola*	22.46	0
821	*L. fasciola*	19.84	1
822	*L. fasciola*	24.01	1
823	*L. fasciola*	19.16	0
824	*L. fasciola*	25.45	1
825	*L. fasciola*	21.26	1
826	*L. fasciola*	18.89	0
827	*L. fasciola*	18.87	0
828	*L. fasciola*	27.52	2
829	*L. fasciola*	19.92	1
830	*L. fasciola*	16.9	0
831	*L. fasciola*	19.29	0
832	*L. fasciola*	19.01	0
833	*L. fasciola*	25.88	2
834	*L. fasciola*	19.56	0

Table A-1. Initial Length and Weight of Translocated Mussels, 10/10/2013. Continued

TagNum	Species	Length (mm)	Weight (g)
835	*L. fasciola*	22.88	2
836	*L. fasciola*	20.77	1
837	*L. fasciola*	23.18	2
838	*L. fasciola*	17.17	1
839	*L. fasciola*	18.11	1

Table A-2. Length and Weight of Translocated Mussels on Interim Survey, 6/10/2014

TagNum	Species	Length (mm)	Weight (g)*
1	*L. fasciola*	27.36	3
7	*L. fasciola*	29.34	
8	*L. fasciola*	25.26	3
14	*L. fasciola*	32.11	5
17	*M. conradicus*	27.39	3
26	*L. fasciola*	27.23	2
29	*L. fasciola*	21.78	1
33	*L. fasciola*	23.84	2
34	*L. fasciola*	26.42	3
35	*L. fasciola*	22.79	1
38	*L. fasciola*	25.71	2.3
48	*L. fasciola*	30.75	4
55	*L. fasciola*	34.73	6.4
57	*L. fasciola*	27.32	4
58	*L. fasciola*	23.59	0.6
60	*L. fasciola*	23.87	2.2
62	*L. fasciola*	29.08	3.6
63	*L. fasciola*	25.44	3
65	*L. fasciola*	26.25	3
67	*L. fasciola*	27.07	2
74	*L. fasciola*	28.24	3
75	*L. fasciola*	24.08	2
83	*L. fasciola*	27.62	3
87	*L. fasciola*	20.65	2
91	*L. fasciola*	28.59	3.4
92	*L. fasciola*	24.76	3
93	*L. fasciola*	28.79	3
94	*L. fasciola*	22.67	1
98	*L. fasciola*	25.03	2
101	*L. fasciola*	34.25	6.2
106	*L. fasciola*		
110	*L. fasciola*	24.86	2
112	*L. fasciola*	30.36	4
117	*L. fasciola*	20.79	1
118	*L. fasciola*	26.17	2
119	*L. fasciola*	24.54	2.3
121	*M. conradicus*	27.36	3
123	*M. conradicus*	24.31	2

Table A-2. Length and Weight of Translocated Mussels on Interim Survey, 6/10/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
124	*L. fasciola*	26.6	3
129	*L. fasciola*	26.6	3
131	*L. fasciola*	19.47	1.2
137	*L. fasciola*	29.06	4
142	*L. fasciola*	26.56	3
146	*L. fasciola*	28.73	3
147	*L. fasciola*	21.5	0.6
156	*L. fasciola*	25.85	3
157	*L. fasciola*	23.89	1.9
162	*L. fasciola*	24.46	2.1
165	*L. fasciola*	25.8	2.8
168	*L. fasciola*	27.37	3
171	*L. fasciola*	23.96	1.9
174	*L. fasciola*	30.6	4
178	*L. fasciola*	29.45	4
184	*L. fasciola*	27.32	4
186	*L. fasciola*	29.14	3
192	*L. fasciola*	29.48	3.7
200	*M. conradicus*	32.82	6
201	*M. conradicus*	24.33	2
204	*L. fasciola*	23.61	2
208	*M. conradicus*	26.41	3
221	*L. fasciola*	25.97	3
222	*L. fasciola*	24.3	2.2
224	*M. conradicus*	25.2	3
225	*L. fasciola*	25.7	3
227	*L. fasciola*	25.72	2.5
242	*L. fasciola*	28.28	3.9
244	*L. fasciola*		
247	*L. fasciola*	25.38	3
251	*L. fasciola*	26.57	2
256	*L. fasciola*	28.44	4
258	*L. fasciola*	22.35	2
259	*L. fasciola*	27.78	4
260	*L. fasciola*	28.11	3
269	*L. fasciola*	27.8	3.1
271	*L. fasciola*	27.49	4

Table A-2. Length and Weight of Translocated Mussels on Interim Survey, 6/10/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
273	*L. fasciola*	22.36	2
285	*L. fasciola*	25.77	2.6
288	*L. fasciola*		
289	*L. fasciola*	21.96	1.6
294	*L. fasciola*	19.95	1.2
305	*L. fasciola*	26.09	2.5
307	*L. fasciola*	27.31	3.2
328	*L. fasciola*	22.71	1.6
335	*L. fasciola*	20.48	1.5
351	*L. fasciola*	25.75	2.7
356	*L. fasciola*	29.09	4
358	*L. fasciola*	26.44	2
359	*L. fasciola*	22.42	1.6
362	*L. fasciola*	26.96	3
364	*L. fasciola*	25.83	2.8
374	*L. fasciola*	23.95	2
378	*L. fasciola*	24.17	2
379	*L. fasciola*	26.77	2.7
381	*L. fasciola*	23.26	1.8
390	*L. fasciola*	25.16	2.5
398	*M. conradicus*	45.79	9.9
408	*M. conradicus*	36.12	
419	*M. conradicus*	32.04	
424	*M. conradicus*	34.12	1.9
437	*M. conradicus*	37.09	4.4
445	*M. conradicus*	34.32	
447	*M. conradicus*	39.58	
450	*M. conradicus*	52.59	
453	*M. conradicus*	34.87	
484	*M. conradicus*	40.46	6.1
515	*M. conradicus*	45.45	8.3
549	*M. conradicus*	33.69	
553	*M. conradicus*	45.84	
556	*M. conradicus*	44.56	
557	*M. conradicus*		
568	*M. conradicus*	43.63	
569	*M. conradicus*	32.06	

Table A-2. Length and Weight of Translocated Mussels on Interim Survey, 6/10/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
570	*M. conradicus*	29.71	2
571	*M. conradicus*	37.79	
573	*M. conradicus*	40.66	6.3
575	*M. conradicus*	42.56	
576	*M. conradicus*	40.81	3.5
579	*M. conradicus*	39.66	
580	*M. conradicus*	39.7	
581	*M. conradicus*	45.24	
588	*M. conradicus*	40.64	
696	*M. conradicus*		
713	*M. conradicus*	45.34	10.9
719	*M. conradicus*		
743	*M. conradicus*		
762	*L. fasciola*	30.79	4.7
769	*L. fasciola*	22.75	1.9
770	*L. fasciola*	21	1.3
773	*L. fasciola*	21.39	1.4
774	*L. fasciola*	24.82	2
793	*L. fasciola*	26.25	2.7
798	*L. fasciola*	26.08	3
803	*L. fasciola*		
805	*L. fasciola*	23.12	2
808	*L. fasciola*	18.75	1
820	*L. fasciola*	26.13	2.5
829	*L. fasciola*	23.52	1.7

*Dead mussels were not weighed. Mussels with a blank weight cell were dead at the second survey.

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014

TagNum	Species	Length (mm)	Weight (g)*
0	*L. fasciola*		
1	*L. fasciola*	29.68	3.393
2	*L. fasciola*	35.5	6.676
3	*L. fasciola*	20.11	
6	*L. fasciola*	34.54	5.703
8	*L. fasciola*	27.3	3.085
9	*L. fasciola*	32.05	4.691
10	*L. fasciola*	23.34	1.977
12	*L. fasciola*	33.14	4.9
14	*L. fasciola*	33.14	4.989
17	*M. conradicus*	30	4.26
19	*L. fasciola*	30.12	4.4
25	*L. fasciola*	29.44	4.013
26	*L. fasciola*	29.38	3.163
29	*L. fasciola*	26.92	2.447
33	*L. fasciola*	26.48	2.75319
34	*L. fasciola*		
35	*L. fasciola*		
38	*L. fasciola*	33.42	5.5
40	*M. conradicus*		
42	*L. fasciola*		
44	*L. fasciola*	58.97	3.315
47	*L. fasciola*	37.64	7.34184
48	*L. fasciola*	32.51	5.71032
52	*L. fasciola*	28.59	2.85516
53	*L. fasciola*	20.79	
54	*L. fasciola*	37.8	8.36154
55	*L. fasciola*	44.13	13.9
57	*L. fasciola*	27.29	1.289
58	*L. fasciola*		
60	*L. fasciola*	24.01	
62	*L. fasciola*	41.04	9.7
63	*L. fasciola*		
65	*L. fasciola*	29.7	3.276
66	*L. fasciola*	20.78	
67	*L. fasciola*	30	3.46698

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
69	*L. fasciola*	31.95	4.38471
70	*L. fasciola*	34.86	6.22017
72	*L. fasciola*		
74	*L. fasciola*	32.36	4.904
75	*L. fasciola*	25.25	2.616
81	*L. fasciola*	33.9	5.60835
83	*L. fasciola*	29.29	3.56895
86	*L. fasciola*	44.35	12.4
87	*L. fasciola*		
88	*M. conradicus*		
91	*L. fasciola*	36.7	7.4
92	*L. fasciola*	27.86	3.0591
93	*L. fasciola*	33.46	5.865
94	*L. fasciola*	24.28	2.113
97	*L. fasciola*	36.75	8.8
98	*L. fasciola*	26.64	2.405
101	*L. fasciola*		
102	*L. fasciola*	29.15	3.565
106	*L. fasciola*		
107	*L. fasciola*	39.14	8.8
108	*L. fasciola*	31.4	4.89456
110	*L. fasciola*	27.23	2.95713
111	*L. fasciola*	30.57	4.18077
112	*L. fasciola*	30.85	4.342
113	*L. fasciola*	35.74	5.71032
117	*L. fasciola*	22.07	1.316
118	*L. fasciola*	29.77	3.36501
119	*L. fasciola*	37.19	7.8
121	*L. fasciola*	28.27	3.11
123	*L. fasciola*	26.94	2.89
124	*L. fasciola*		
125	*L. fasciola*	27.23	2.598
126	*L. fasciola*	27.59	2.24334
129	*L. fasciola*	37.83	8.6
130	*L. fasciola*	27.54	2.85516
131	*L. fasciola*	29.87	4.1
132	*L. fasciola*	29.09	3
133	*M. conradicus*		

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
137	*L. fasciola*	31.36	4.69062
140	*L. fasciola*	28.68	2.396
142	*L. fasciola*		
144	*L. fasciola*	26.36	1.83546
146	*L. fasciola*		
147	*L. fasciola*		
149	*L. fasciola*		
152	*L. fasciola*	29.73	3.26304
154	*L. fasciola*	31.21	3.981
156	*L. fasciola*	30.13	4.334
157	*L. fasciola*	35.83	7
158	*L. fasciola*	35.21	6.8
160	*L. fasciola*	43.38	
162	*L. fasciola*	36.64	6.9
165	*L. fasciola*	36.52	7
167	*L. fasciola*	42	11.6
168	*L. fasciola*	29.83	3.87486
171	*L. fasciola*	28.27	3.8
173	*L. fasciola*	26.03	
174	*L. fasciola*		
175	*L. fasciola*	30.62	4.189
178	*L. fasciola*	32.03	3.927
180	*L. fasciola*	24.41	1.833
181	*L. fasciola*	34.31	
182	*L. fasciola*	33.19	4.9
183	*L. fasciola*	35.74	5.91426
184	*L. fasciola*	27.33	1.413
186	*L. fasciola*	26.93	
188	*M. conradicus*		
192	*L. fasciola*	41.15	10.4
195	*L. fasciola*	25.79	2.593
200	*M. conradicus*	35.63	6.49
201	*M. conradicus*	26.59	2.321
204	*L. fasciola*		
206	*L. fasciola*	33.56	4.99653
208	*M. conradicus*	27.63	2.76
217	*L. fasciola*	31.67	4.222
218	*L. fasciola*	23.46	1.906

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
219	*L. fasciola*	41.78	8.8
221	*L. fasciola*		
222	*L. fasciola*	34.52	6.5
224	*M. conradicus*	26.97	2.503
225	*L. fasciola*		
226	*L. fasciola*	33.55	6.4
227	*L. fasciola*	33.71	6.2
231	*L. fasciola*	24.48	1.847
233	*L. fasciola*	35.17	6.189
239	*L. fasciola*	34.28	5.1
242	*L. fasciola*	37.25	8.8
244	*L. fasciola*		
245	*L. fasciola*	27.79	2.54925
247	*L. fasciola*		
248	*L. fasciola*	19.08	
250	*L. fasciola*	33.45	5.16
251	*L. fasciola*	27.52	2.956
253	*L. fasciola*	34.39	6.1182
255	*L. fasciola*	37.66	8.5
256	*L. fasciola*	36.92	8.3
257	*L. fasciola*	38.13	8.4
258	*L. fasciola*		
259	*L. fasciola*		
260	*L. fasciola*	31.59	3.911
261	*M. conradicus*		
264	*L. fasciola*	29.59	7.03593
268	*L. fasciola*	32.84	5.317
269	*L. fasciola*	40.68	9.8
271	*L. fasciola*	30.56	4.224
273	*L. fasciola*	22.81	1.541
279	*L. fasciola*	39.34	7.2
283	*L. fasciola*	37.69	8.5
285	*L. fasciola*	35.72	6.5
288	*L. fasciola*		
289	*L. fasciola*	32.32	5.3
291	*L. fasciola*	45.26	8.144
293	*L. fasciola*	31.6	4.5
294	*L. fasciola*	28.95	3.5

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
300	*L. fasciola*	19.08	
301	*L. fasciola*	20.88	
304	*L. fasciola*	41.43	10.9
305	*L. fasciola*	36.34	6.6
307	*L. fasciola*	38.65	8.4
309	*L. fasciola*	31.93	4.5
320	*L. fasciola*	21.63	
322	*L. fasciola*	29.26	
324	*L. fasciola*	32.3	4.9
328	*L. fasciola*	33.14	5.5
332	*L. fasciola*	29.62	3.6
335	*L. fasciola*	32.05	5.1
338	*L. fasciola*	34.7	6.149
339	*L. fasciola*	26.04	
340	*L. fasciola*		
342	*L. fasciola*		
344	*L. fasciola*	22.47	1.627
345	*L. fasciola*		
350	*L. fasciola*	38.26	3.46698
351	*L. fasciola*	30.31	5.1
352	*L. fasciola*		3.958
354	*L. fasciola*		
356	*L. fasciola*	32.08	4.89456
357	*L. fasciola*	28.88	3.271
358	*L. fasciola*	27.66	2.768
359	*L. fasciola*	29.55	3.7
362	*L. fasciola*	28.62	3.36501
364	*L. fasciola*	32.61	5.8
366	*L. fasciola*	28.01	3.283
368	*L. fasciola*	35.17	5.403
374	*L. fasciola*	26.78	2.29
378	*L. fasciola*	28.05	2.982
379	*L. fasciola*	37.86	8.3
381	*L. fasciola*	22.8	5.7
384	*L. fasciola*	26.16	
385	*L. fasciola*	35.21	6.1
386	*L. fasciola*	28.23	3.061
387	*L. fasciola*	29.23	3.749

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
388	*L. fasciola*		
390	*L. fasciola*	33.83	6
392	*L. fasciola*	20.02	
395	*L. fasciola*	29.73	3.7
398	*M. conradicus*	47.68	10
406	*M. conradicus*	44.1	10
408	*M. conradicus*		
419	*M. conradicus*		
422	*M. conradicus*	41.33	5.799
423	*M. conradicus*	41.49	6.48
424	*M. conradicus*		
429	*M. conradicus*	48.05	12
435	*M. conradicus*	29.45	1
437	*M. conradicus*	37.93	4.495
445	*M. conradicus*		
447	*M. conradicus*		
448	*M. conradicus*	47.74	12.1
449	*M. conradicus*	47.42	9.4
450	*M. conradicus*		
452	*M. conradicus*	45.72	6.7
453	*M. conradicus*		
461	*M. conradicus*	48.29	10.3
462	*M. conradicus*	42.66	6.2
464	*M. conradicus*	48.88	
480	*M. conradicus*	41.8	2.8
483	*M. conradicus*	40.88	5.5
484	*M. conradicus*	43.11	7
488	*M. conradicus*	33.02	3
505	*M. conradicus*	45.9	12.688
507	*M. conradicus*		
509	*M. conradicus*		
515	*M. conradicus*	47.63	9.3
516	*M. conradicus*		
517	*M. conradicus*	45	10.7
521	*M. conradicus*	39.24	5.21
525	*M. conradicus*	36.09	4.2
548	*M. conradicus*	46.93	10.248
549	*M. conradicus*		

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
550	*M. conradicus*	48.54	
553	*M. conradicus*		
556	*M. conradicus*		
557	*M. conradicus*		
560	*M. conradicus*	45.14	
561	*M. conradicus*	42.85	8.653
562	*M. conradicus*	43.28	7.101
568	*M. conradicus*		
569	*M. conradicus*		
570	*M. conradicus*	32.39	2.135
571	*M. conradicus*		
572	*M. conradicus*	25.31	1.194
573	*M. conradicus*	42.63	6.9
574	*M. conradicus*	46.81	10.1
575	*M. conradicus*		
576	*M. conradicus*		
577	*M. conradicus*	38.01	5.829
578	*M. conradicus*	34.86	
579	*M. conradicus*		
580	*M. conradicus*	41.14	6.2
581	*M. conradicus*		
585	*M. conradicus*	27.45	9.368
586	*M. conradicus*	32.27	3.263
588	*M. conradicus*		
593	*M. conradicus*		
596	*M. conradicus*	43.51	7.7
605	*M. conradicus*		
607	*M. conradicus*		
612	*M. conradicus*	50.92	
613	*M. conradicus*	32.85	3.177
615	*M. conradicus*	45.79	
624	*M. conradicus*	41.55	7.8
630	*M. conradicus*	42.92	8
647	*M. conradicus*	33.97	3.7
657	*M. conradicus*		
661	*M. conradicus*	48.14	7.8
668	*M. conradicus*	40.25	5.2
669	*M. conradicus*	33.25	

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
671	*M. conradicus*	49.53	11.8
673	*M. conradicus*	41.63	7.4
677	*M. conradicus*	46.17	9.2
680	*M. conradicus*	47.01	
682	*M. conradicus*	38.85	4.4
691	*M. conradicus*	36.43	4.8
695	*M. conradicus*	45.21	8.3
696	*M. conradicus*		
700	*M. conradicus*	44.38	7.4
712	*M. conradicus*	50.87	
713	*M. conradicus*	46.67	11
715	*M. conradicus*	40.05	
716	*M. conradicus*	38.59	4.9
719	*M. conradicus*		
743	*M. conradicus*		
761	*L. fasciola*	33.49	5.8
762	*L. fasciola*	39.97	10.3
769	*L. fasciola*		
770	*L. fasciola*	33.85	4.5
771	*L. fasciola*	34.79	5.8
773	*L. fasciola*	35.05	6.7
774	*L. fasciola*	31.37	5.1
777	*L. fasciola*	38.2	7.8
779	*L. fasciola*	21.46	
780	*L. fasciola*	38.05	8.5
781	*L. fasciola*	36.13	6.6
783	*L. fasciola*	35.08	6.1
784	*L. fasciola*	39.26	9.5
787	*L. fasciola*	38.87	8.4
792	*L. fasciola*	32.61	5.2
793	*L. fasciola*	37.6	7
798	*L. fasciola*	37.6	8.5
802	*L. fasciola*	40.53	11.5
803	*L. fasciola*		
805	*L. fasciola*	35.7	7.1
808	*L. fasciola*	26.28	2.9
820	*L. fasciola*	40.15	9.6
829	*L. fasciola*	34.16	5.7

Table A-3. Length and Weight of Translocated Mussels on Final Survey, 9/23/2014. Continued

TagNum	Species	Length (mm)	Weight (g)*
836	*L. fasciola*	39.21	8
837	*L. fasciola*	38.02	5.6

*Dead mussels were not weighed. Mussels with a blank weight cell were dead at the final survey.

Appendix B. Analysis of Survival Rate Effects

Table B-1. Survival Rate Full Model, RBD Split-Split Plot Repeated Measures without Replication on the Arcsin Transformed Values, Block on Destination - Data

Obs	Destination	Species	House	Time	Survived	Trials	Survival_Rate	Arcsin_SR
1	0	0	0	1	48	48	1	1.57080
2	0	0	0	2	41	48	0.8541667	1.02395
3	0	0	0	3	36	48	0.75	0.84806
4	0	0	1	1	60	60	1	1.57080
5	0	0	1	2	55	60	0.9166667	1.15966
6	0	0	1	3	42	60	0.7	0.77540
7	0	1	0	1	40	40	1	1.57080
8	0	1	0	2	22	40	0.55	0.58236
9	0	1	0	3	15	40	0.375	0.38440
10	0	1	1	1	20	20	1	1.57080
11	0	1	1	2	17	20	0.85	1.01599
12	0	1	1	3	6	20	0.3	0.30469
13	1	0	0	1	48	48	1	1.57080
14	1	0	0	2	34	48	0.7083333	0.78713
15	1	0	0	3	32	48	0.6666667	0.72973
16	1	0	1	1	60	60	1	1.57080
17	1	0	1	2	51	60	0.85	1.01599
18	1	0	1	3	39	60	0.65	0.70758
19	1	1	0	1	40	40	1	1.57080
20	1	1	0	2	26	40	0.65	0.70758
21	1	1	0	3	21	40	0.525	0.55272
22	1	1	1	1	20	20	1	1.57080
23	1	1	1	2	20	20	1	1.57080
24	1	1	1	3	14	20	0.7	0.77540

Table B-2. Survival Rate Full Model - Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Species	1	2	0.65	0.5060
House	1	2	5.25	0.1490
Species*House	1	2	2.46	0.2573
Time	2	8	123.24	<.0001
Species*Time	2	8	2.83	0.1177
House*Time	2	8	7.69	0.0137
Species*House*Time	2	8	2.02	0.1951

Table B-3. Effect = Time, Method = LSD (P<0.05), Set = 4, Survival Rate Full Model

Obs	Species	House	Time	Esti-mate	Standard Error	Mean	Standard Error of Mean	Letter Group
9	_	_	1	1.5708	0.06920	1.5708	0.06920	A
10	_	_	2	0.9829	0.06920	0.9829	0.06920	B
11	_	_	3	0.6347	0.06920	0.6347	0.06920	C

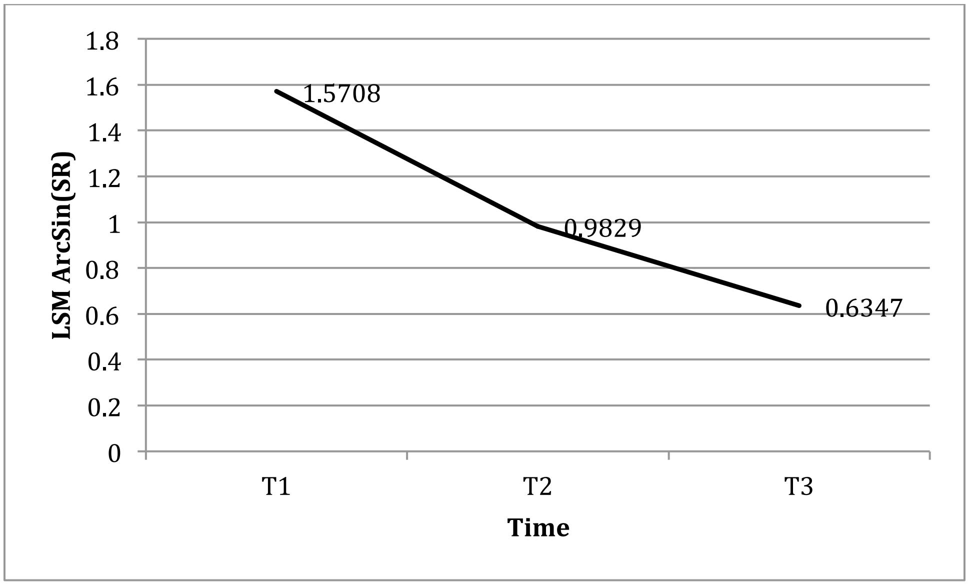
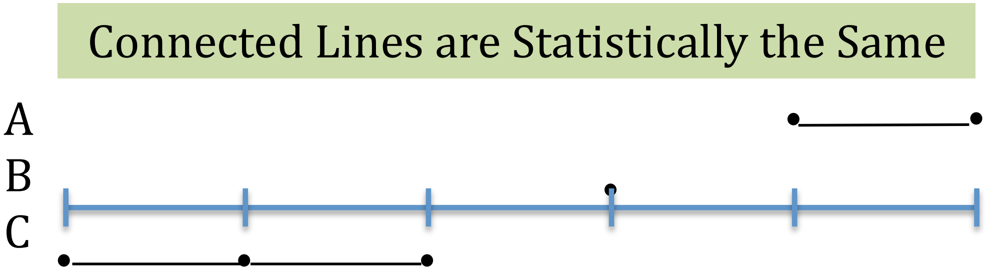


Figure B-1. Least Squared Means (LSM) for Survival Rate, Effect = Time, Full Model

Table B-4. Effect = House*Time, Method = LSD (P<0.05), Set = 6, Survival Rate Full Model

Obs	Spec-ies	House	Time	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
18	_	0	1	1.5708	0.08346	1.5708	0.08346	A
19	_	0	2	0.7753	0.08346	0.7753	0.08346	C
20	_	0	3	0.6287	0.08346	0.6287	0.08346	C
21	_	1	1	1.5708	0.08346	1.5708	0.08346	A
22	_	1	2	1.1906	0.08346	1.1906	0.08346	B
23	_	1	3	0.6408	0.08346	0.6408	0.08346	C



House	0	1	0	1	0	1
Time	3	3	2	2	1	1

Figure B-2. LSM for Effect = House*Time, Survival Rate Full Model

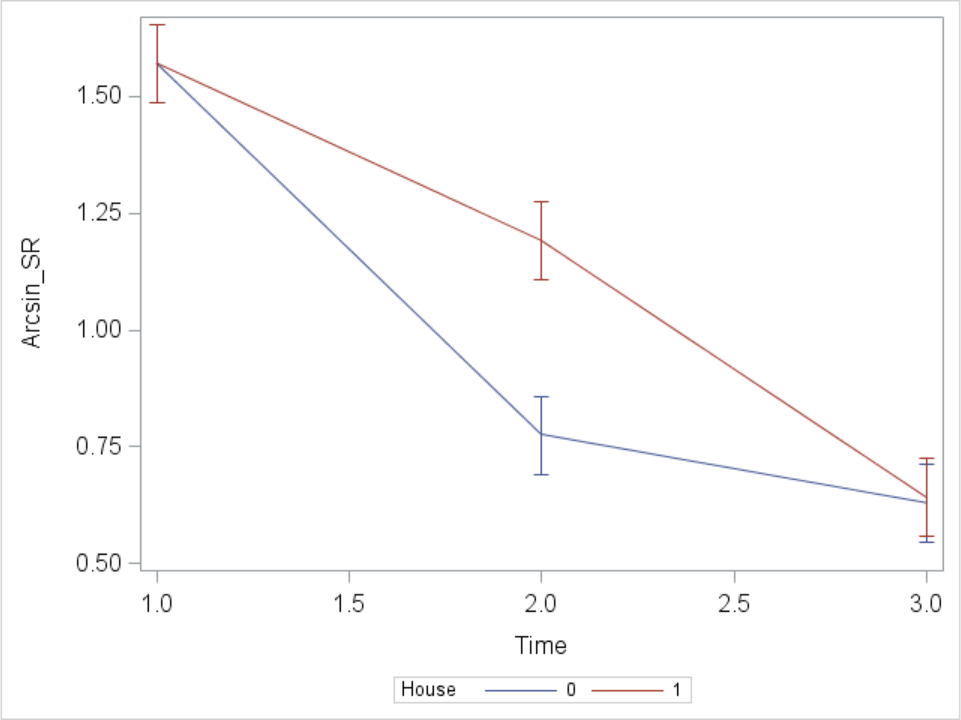


Figure B-3. Time*House LSM for Arcsin_SR, Survival Rate Full Model

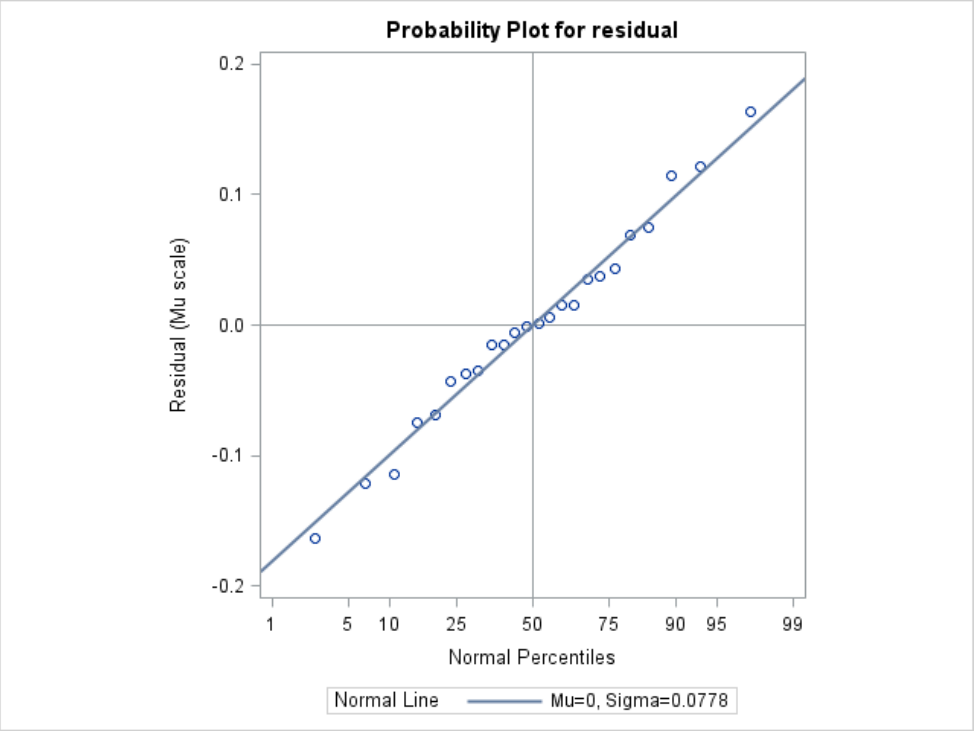


Figure B-4. Normality of Arcsin(Survival Rate) Residuals, Full Model

Table B-5. Full Survival Rate Model Assumptions are Met

*** Diagnostic Summary ***
No severe outliers or influential points found
Normality should be satisfactory
Equal variance should be satisfactory

Table B-6. *L. fasciola* Survival Rate Model Assumptions are Met

*** Diagnostic Summary ***
No severe outliers or influential points found
Normality should be satisfactory
Equal variance should be satisfactory

Table B-7. ***M. conradicus*** **Survival Rate Model Assumptions are Met**

*** Diagnostic Summary ***
No severe outliers or influential points found
Normality might be an issue, KS>0.10; Shapiro-Wilkes test indicates Normality
Equal variance should be satisfactory

Table B-8. ***L. fasciola*** **Survival Model - Type III Tests of Fixed Effects**

Effect	Num DF	Den DF	F Value	Pr > F
House	1	5	1.45	0.2824
Time	2	5	164.58	<.0001
House*Time	2	5	3.52	0.1113

Table B-9. ***M. conradicus*** **Survival Model - Type III Tests of Fixed Effects**

Effect	Num DF	Den DF	F Value	Pr > F
House	1	1	3.87	0.2994
Time	2	4	47.13	0.0017
House*Time	2	4	5.21	0.0770

Appendix C. Analysis of Growth Rate Effects

Table C-1. Absolute Growth Rate Data

TagNum	Destination	Species	House	30 day Absolute Growth Rate
251	0	0	0	0.10862069
94	0	0	0	0.140517241
117	0	0	0	0.149137931
1	0	0	0	0.150862069
112	0	0	0	0.154310345
195	0	0	0	0.168965517
358	0	0	0	0.170689655
26	0	0	0	0.197413793
8	0	0	0	0.218965517
273	0	0	0	0.220689655
98	0	0	0	0.225
231	0	0	0	0.243103448
14	0	0	0	0.255172414
178	0	0	0	0.295689655
65	0	0	0	0.304310345
125	0	0	0	0.306896552
374	0	0	0	0.35
75	0	0	0	0.368965517
74	0	0	0	0.412068966
180	0	0	0	0.414655172
25	0	0	0	0.437068966
218	0	0	0	0.437931034
338	0	0	0	0.450862069
271	0	0	0	0.454310345
260	0	0	0	0.468965517
102	0	0	0	0.504310345
93	0	0	0	0.512068966
357	0	0	0	0.513793103
378	0	0	0	0.530172414
6	0	0	0	0.536206897
366	0	0	0	0.551724138
154	0	0	0	0.620689655
387	0	0	0	0.65

Table C-1. Absolute Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Absolute Growth Rate
386	0	0	0	0.725
97	0	0	0	1.20862069
291	0	0	0	2.162931034
144	0	0	1	-0.086206897
344	0	0	1	0.121551724
48	0	0	1	0.144827586
10	0	0	1	0.289655172
362	0	0	1	0.29137931
110	0	0	1	0.303448276
67	0	0	1	0.314655172
83	0	0	1	0.343965517
137	0	0	1	0.355172414
233	0	0	1	0.360344828
245	0	0	1	0.372413793
168	0	0	1	0.375862069
111	0	0	1	0.376724138
92	0	0	1	0.38362069
356	0	0	1	0.430172414
206	0	0	1	0.445689655
33	0	0	1	0.450862069
52	0	0	1	0.457758621
108	0	0	1	0.465517241
156	0	0	1	0.493103448
81	0	0	1	0.504310345
368	0	0	1	0.511206897
69	0	0	1	0.512931034
268	0	0	1	0.515517241
118	0	0	1	0.522413793
250	0	0	1	0.54137931
152	0	0	1	0.544827586
253	0	0	1	0.555172414
113	0	0	1	0.571551724
130	0	0	1	0.575862069
2	0	0	1	0.585344828
175	0	0	1	0.606896552
70	0	0	1	0.625
9	0	0	1	0.65862069

Table C-1. Absolute Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Absolute Growth Rate
264	0	0	1	0.668965517
54	0	0	1	0.674137931
140	0	0	1	0.720689655
183	0	0	1	0.725
29	0	0	1	0.775
47	0	0	1	0.807758621
217	0	0	1	0.879310345
350	0	0	1	1.451724138
44	0	0	1	3.280172414
585	0	1	0	-1.6
562	0	1	0	-0.169827586
577	0	1	0	-0.051724138
521	0	1	0	-0.045689655
505	0	1	0	-0.021551724
586	0	1	0	0
423	0	1	0	0.009482759
548	0	1	0	0.011206897
422	0	1	0	0.013793103
437	0	1	0	0.063793103
572	0	1	0	0.288793103
570	0	1	0	0.321551724
561	0	1	0	0.438793103
615	0	1	0	1.114655172
121	0	1	1	0.109482759
224	0	1	1	0.218965517
200	0	1	1	0.464655172
208	0	1	1	0.482758621
17	0	1	1	0.493103448
774	1	0	0	0.648275862
132	1	0	0	0.661206897
19	1	0	0	0.79137931
182	1	0	0	0.807758621
364	1	0	0	0.839655172
395	1	0	0	0.870689655
324	1	0	0	0.89137931
390	1	0	0	0.91637931
309	1	0	0	0.927586207

Table C-1. Absolute Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Absolute Growth Rate
226	1	0	0	0.948275862
792	1	0	0	1.00862069
780	1	0	0	1.038793103
242	1	0	0	1.051724138
279	1	0	0	1.063793103
781	1	0	0	1.121551724
771	1	0	0	1.124137931
239	1	0	0	1.143965517
777	1	0	0	1.187068966
55	1	0	0	1.209482759
86	1	0	0	1.23362069
379	1	0	0	1.260344828
837	1	0	0	1.279310345
256	1	0	0	1.287931034
304	1	0	0	1.318965517
285	1	0	0	1.349137931
802	1	0	0	1.368965517
219	1	0	0	1.464655172
820	1	0	0	1.525
129	1	0	0	1.531034483
62	1	0	0	1.549137931
257	1	0	0	1.556034483
167	1	0	0	1.58362069
836	1	0	0	1.589655172
381	1	0	1	-0.075
171	1	0	1	0.368965517
351	1	0	1	0.398275862
38	1	0	1	0.676724138
91	1	0	1	0.706034483
332	1	0	1	0.715517241
294	1	0	1	0.772413793
808	1	0	1	0.804310345
359	1	0	1	0.903448276
131	1	0	1	0.927586207
305	1	0	1	0.944827586
12	1	0	1	0.971551724
293	1	0	1	0.973275862

Table C-1. Absolute Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Absolute Growth Rate
335	1	0	1	0.99137931
307	1	0	1	1.014655172
227	1	0	1	1.034482759
162	1	0	1	1.04137931
192	1	0	1	1.05
222	1	0	1	1.079310345
157	1	0	1	1.080172414
119	1	0	1	1.104310345
107	1	0	1	1.139655172
269	1	0	1	1.145689655
784	1	0	1	1.146551724
289	1	0	1	1.153448276
328	1	0	1	1.15862069
770	1	0	1	1.162931034
787	1	0	1	1.164655172
283	1	0	1	1.215517241
158	1	0	1	1.21637931
793	1	0	1	1.224137931
829	1	0	1	1.227586207
385	1	0	1	1.271551724
783	1	0	1	1.323275862
165	1	0	1	1.379310345
798	1	0	1	1.409482759
761	1	0	1	1.412068966
255	1	0	1	1.413793103
773	1	0	1	1.421551724
762	1	0	1	1.485344828
805	1	0	1	1.93362069
657	1	1	0	-0.425
406	1	1	0	-0.043965517
435	1	1	0	-0.001724138
716	1	1	0	0.038793103
580	1	1	0	0.114655172
398	1	1	0	0.14137931
448	1	1	0	0.144827586
515	1	1	0	0.147413793
573	1	1	0	0.147413793

Table C-1. Absolute Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Absolute Growth Rate
630	1	1	0	0.281034483
700	1	1	0	0.484482759
713	1	1	0	0.520689655
691	1	1	0	0.55
695	1	1	0	0.578448276
449	1	1	0	0.601724138
484	1	1	0	0.668103448
452	1	1	0	0.711206897
483	1	1	0	0.771551724
596	1	1	0	1.218103448
480	1	1	0	1.489655172
647	1	1	1	-0.610344828
517	1	1	1	0.038793103
574	1	1	1	0.118103448
525	1	1	1	0.239655172
661	1	1	1	0.25862069
668	1	1	1	0.275
429	1	1	1	0.447413793
671	1	1	1	0.498275862
673	1	1	1	0.531034483
461	1	1	1	0.569827586
677	1	1	1	0.570689655
462	1	1	1	0.621551724
682	1	1	1	0.830172414
488	1	1	1	0.831034483

Table C-2. Absolute Growth Rate Summary Statistics

Destination	Species	House	N Obs	Mean	Std Dev	Min	Max
0	0	0	36	0.43	0.37	0.11	2.16
		1	43	0.57	0.49	-0.09	3.28
	1	0	14	0.03	0.57	-1.60	1.11
		1	5	0.35	0.18	0.11	0.49
1	0	0	33	1.16	0.28	0.65	1.59
		1	41	1.06	0.34	-0.08	1.93
	1	0	20	0.41	0.45	-0.43	1.49
		1	14	0.37	0.37	-0.61	0.83

Key	Obs	Observation number
	TagNum	Tag Number of mussel
	Length	Length of mussel (mm)
	LifeStatus	Live (1) or Dead (0)
	SCStatus	Silo or Cage Status: 0 Not Silted 1 Lightly Silted 2 Moderately Silted 3 Heavily Silted
	Destination	Location mussel translocated to 0 Pigeon River 1 Nolichucky River
	Species	Mussel Species 0 *Lampsilis fasciola* 1 *Medionidus conradicus*
	House	Housing mussels placed in 0 Cage 1 Silo
	Time	Observation Time 1 9/10/2013 2 6/10/2014 3 9/23/2014
	Replication	Replication number of the (Destination, Species, House, Time) instance

Table C-3. SAS GLIMMIX Procedure Full AGR_{30} Model Information

Data Set	WORKS.RANKS
Response Variable	RankGrowthRate
Response Distribution	Gaussian
Link Function	Identity
Variance Function	Default
Variance Matrix	Not blocked
Estimation Technique	Restricted Maximum Likelihood
Degrees of Freedom Method	Containment

Table C-4. Type III Tests of Fixed Effects, Full AGR_{30} Model

Effect	Num DF	Den DF	F Value	Pr > F
Destination	1	96.87	24.70	<.0001
Species	1	40.73	25.01	<.0001
Destination*Species	1	40.73	24.36	<.0001
House	1	85.05	28.63	<.0001
Destination*House	1	85.05	20.21	<.0001
Species*House	1	85.05	50.74	<.0001
Destination*Species*House	1	85.05	0.09	0.7614

Num DF: Demoninator degrees of freedom
Den DF: Numerator degrees of freedom
Pr > F (p-value < α, α = 0.05)

Table C-5. Mean separation for Rank Absolute Growth Rate in Full AGR_{30} Model

Set	Average Sig Diff Value	Minimum Sig Diff Value	Maximum Sig Diff Value
1	19.462	19.462	19.462
2	12.738	12.738	12.738
3	28.9059	22.0691	36.4885
4	6.02438	6.02438	6.02438
5	22.1534	9.19441	28.4079
6	16.3418	6.98988	20.4908
7	34.1072	11.5577	49.8541

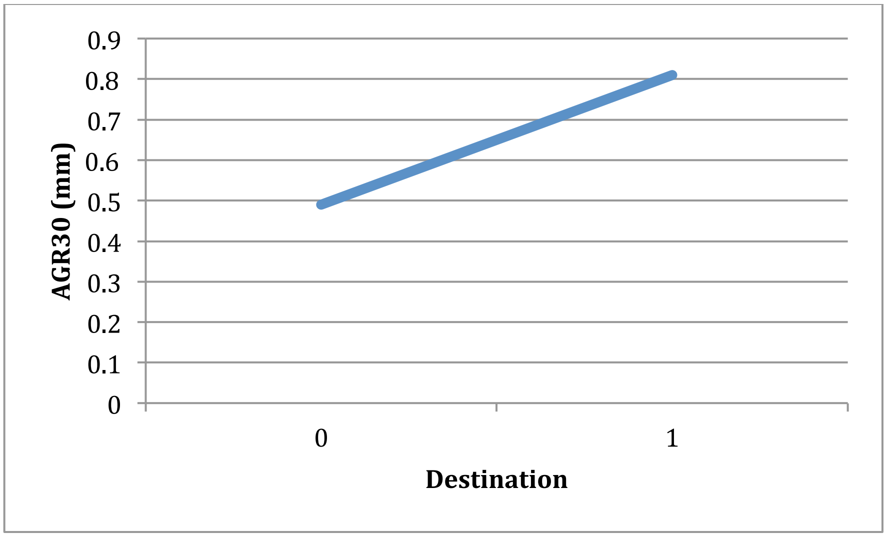


Figure C-1. LSM for Destination, Full AGR$_{30}$ Model

Table C-6. Mean Separation for Rank Absolute Growth Rate, Effect=Destination, Full AGR$_{30}$ Model

Method=Bonferroni(P<0.05) Set=1

Obs	Destin-ation	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
1	0	84.2069	7.1912	84.2069	7.1912	B
2	1	132.95	6.6662	132.95	6.6662	A

Table C-7. Mean Separation for Rank Absolute Growth Rate, Effect=Species, Full AGR$_{30}$ Model

Method=Bonferroni(P<0.05) Set=2

Obs	Species	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
3	0	124.34	4.6798	124.34	4.6798	A
4	1	92.8084	6.7867	92.8084	6.7867	B

Table C-8. Mean Separation for Rank Absolute Growth Rate, Effect=Destination*Species, Full AGR_{30} Model

Method=Bonferroni(P<0.05) Set=3

Obs	Destin-ation	Species	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
5	0	0	84.4128	6.5342	84.4128	6.5342	B
6	0	1	84.0010	10.4499	84.0010	10.4499	B
7	1	0	164.27	6.7012	164.27	6.7012	A
8	1	1	101.62	8.6623	101.62	8.6623	B

Table C-9. Mean Separation for Rank Absolute Growth Rate, Effect=House, Full AGR_{30} Model

Method=Bonferroni(P<0.05) Set=4

Obs	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
9	0	100.47	4.9571	100.47	4.9571	B
10	1	116.68	5.3003	116.68	5.3003	A

Table C-10. Mean Separation for Rank Absolute Growth Rate, Effect=Destination*House, Full AGR_{30} Model

Method=Bonferroni(P<0.05) Set=5

Obs	Destin-ation	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
11	0	0	69.2897	7.1812	69.2897	7.1812	C
12	0	1	99.1241	8.0275	99.1241	8.0275	B
13	1	0	131.65	6.8354	131.65	6.8354	A
14	1	1	134.24	6.9233	134.24	6.9233	A

Table C-11. Mean Separation for Rank Absolute Growth Rate, Effect=Species*House, Full AGR_{30} Model

Method=Bonferroni(P<0.05) Set=6

Obs	Species	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
15	0	0	127.03	4.9132	127.03	4.9132	A
16	0	1	121.66	4.7954	121.66	4.7954	A
17	1	0	73.9105	6.7518	73.9105	6.7518	B
18	1	1	111.71	7.8459	111.71	7.8459	A

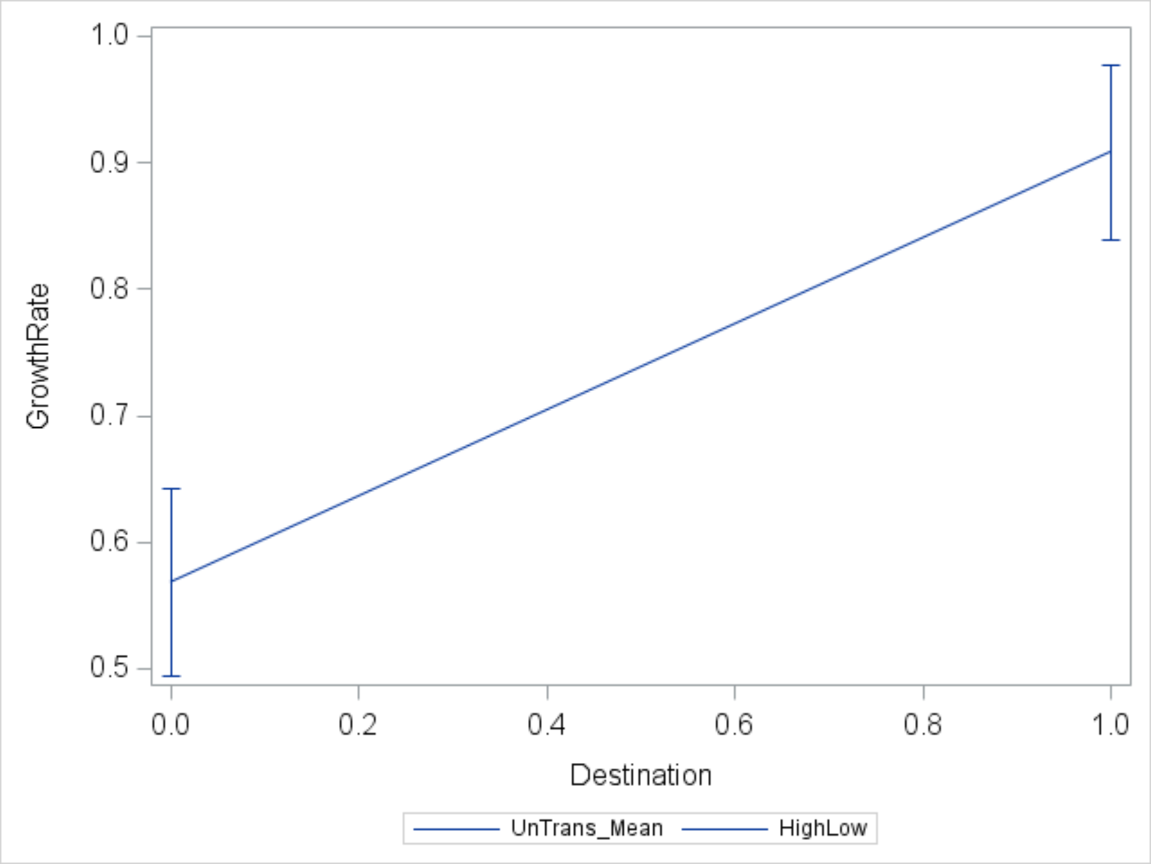


Figure C-2. Destination untransformed LSM for Absolute Growth Rate, Full AGR_{30} Model

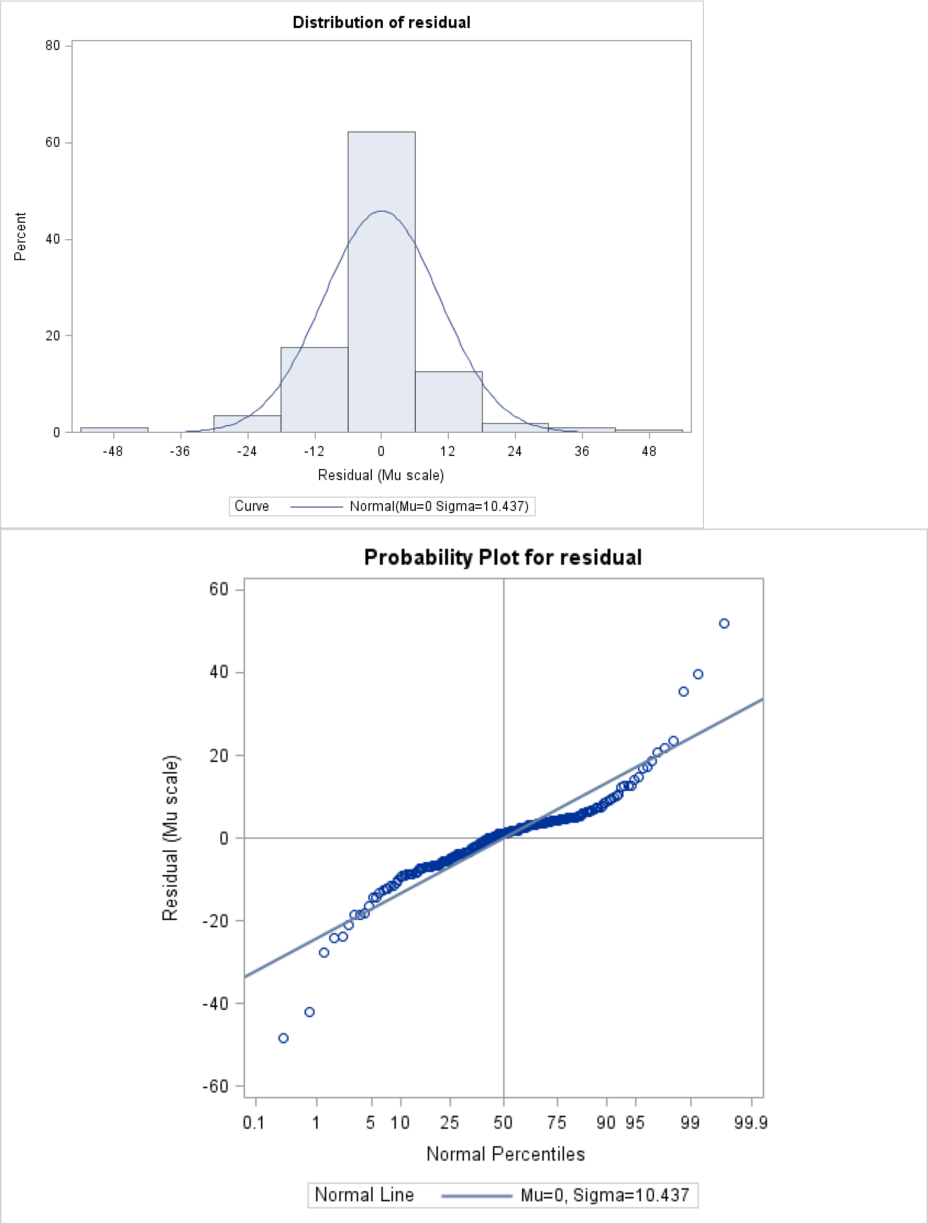


Figure C-3. Check on Normality for Rank Absolute Growth Rate, Full AGR_{30} Model

Figure C-4. Rank Absolute Growth Rate LSM for Species, Full AGR_{30} Model

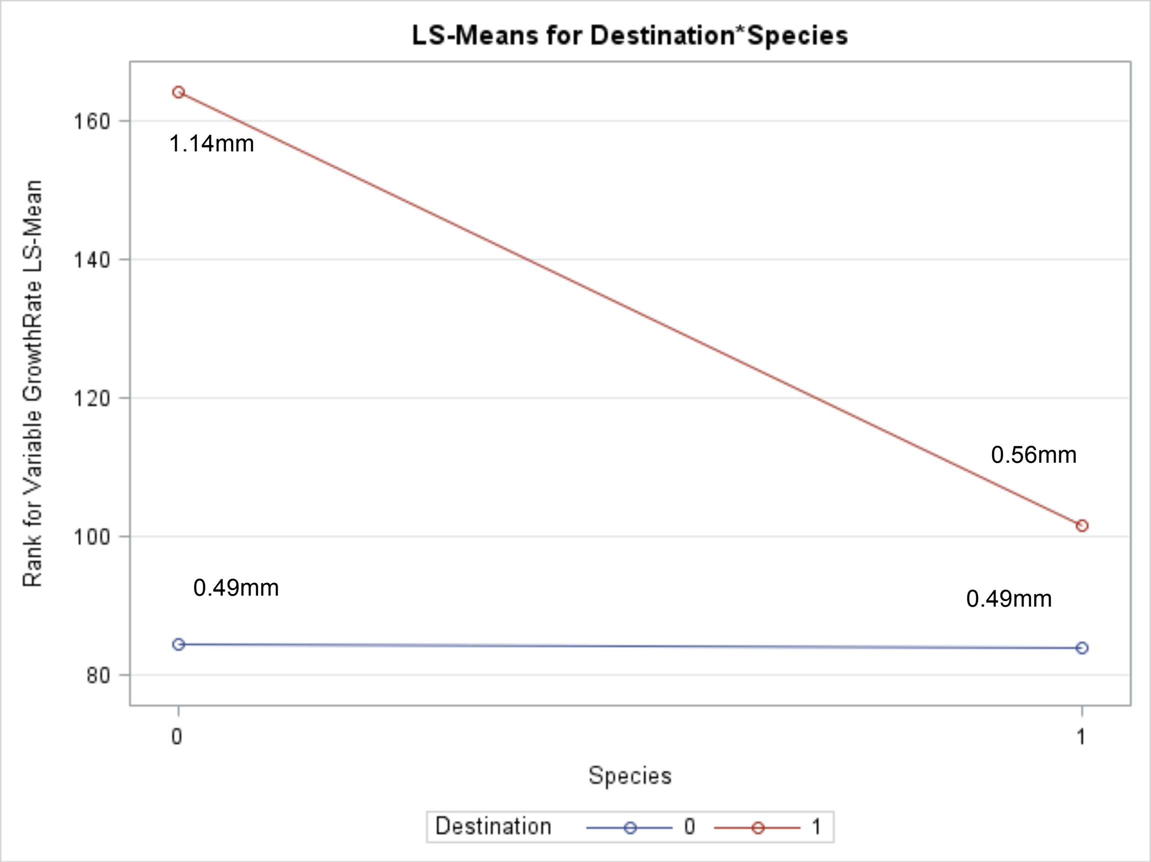


Figure C-5. Rank Absolute Growth Rate LSM for Destination*Species, Full AGR_{30} Model

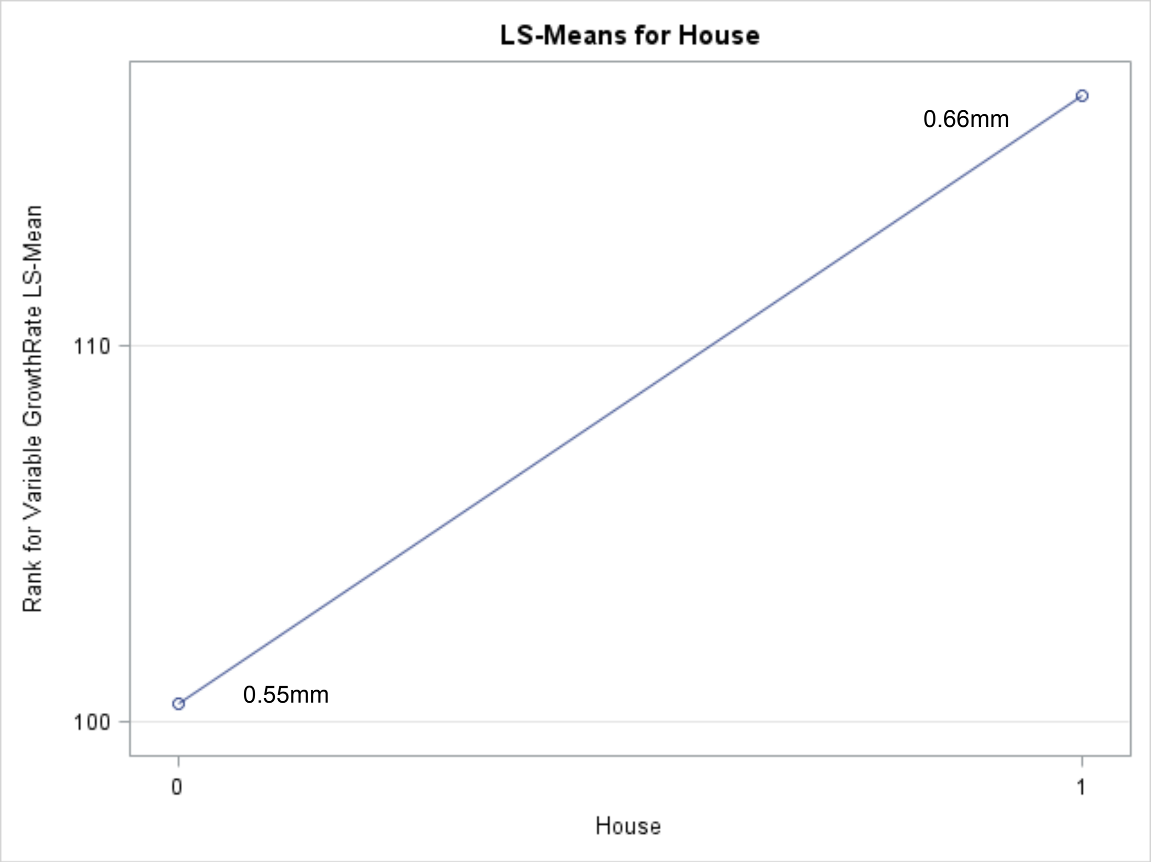


Figure C-6. Rank Absolute Growth Rate LSM for House, Full AGR_{30} Model

Figure C-7. Rank Absolute Growth Rate LSM for Destination*House, Full AGR_{30} Model

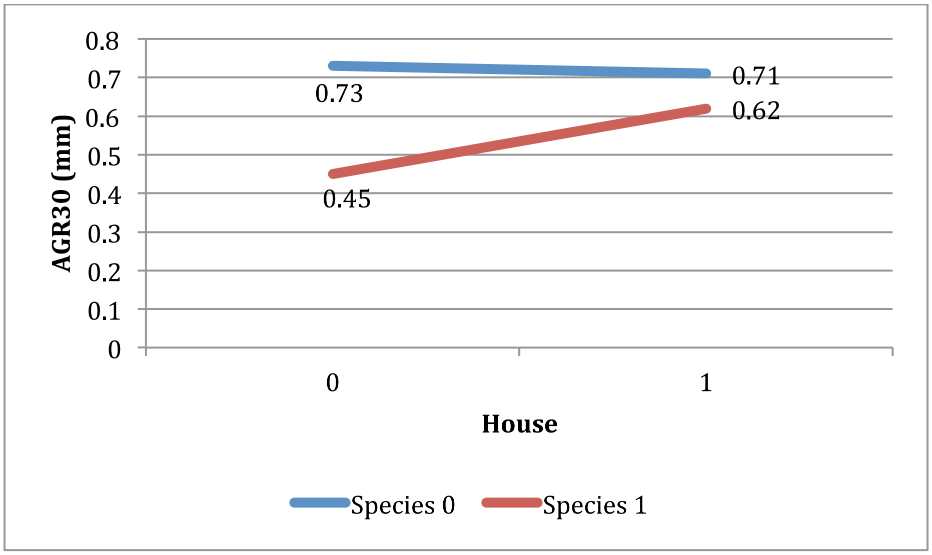


Figure C-8. Absolute Growth Rate LSM for Species*House, Full AGR_{30} Model

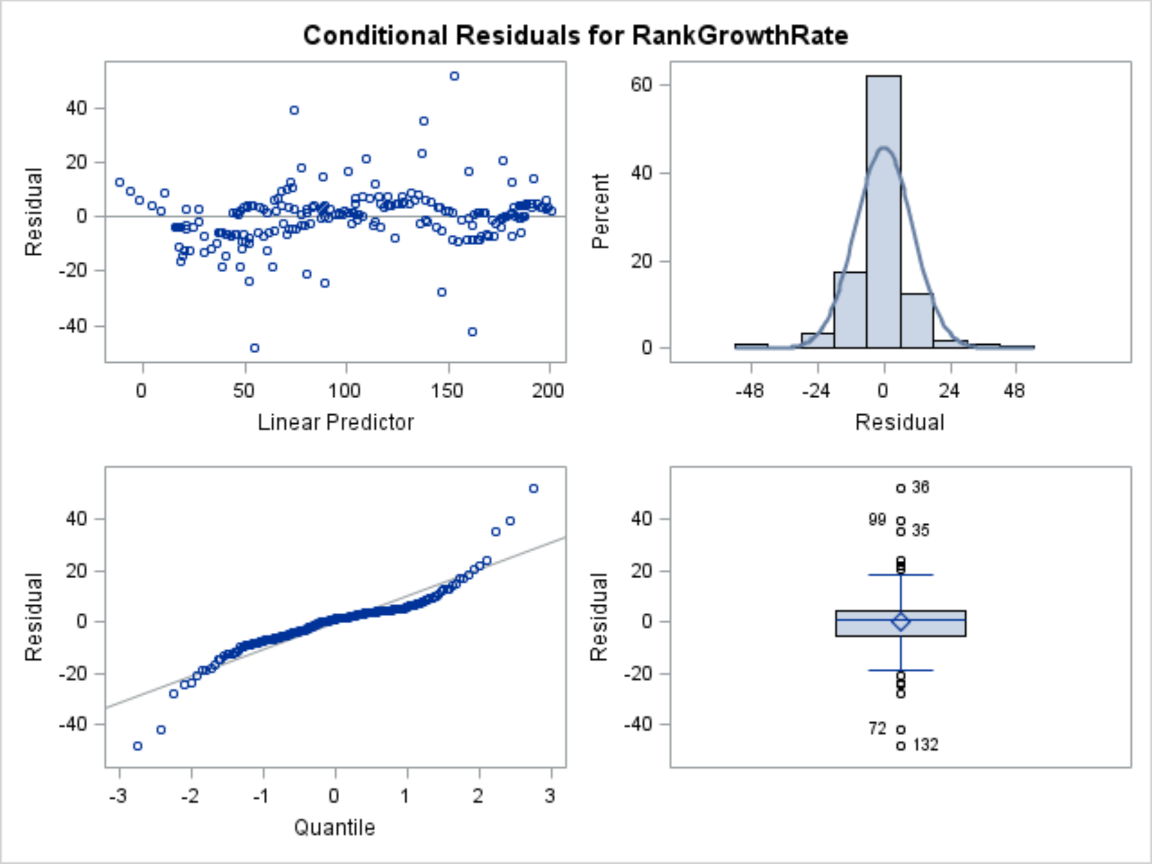


Figure C-9. Conditional Residuals for Rank Absolute Growth Rate, Full Model

Table C-12. Relative Growth Rate Data.

TagNum	Destination	Species	House	30 day Relative Growth Rate
251	0	0	0	0.004136355
112	0	0	0	0.00531006
1	0	0	0	0.005401435
94	0	0	0	0.006203852
358	0	0	0	0.006646793
195	0	0	0	0.007090454
26	0	0	0	0.007287331
117	0	0	0	0.007332248
14	0	0	0	0.008455017
8	0	0	0	0.008843518
98	0	0	0	0.009363296
178	0	0	0	0.010338799
273	0	0	0	0.010898255
231	0	0	0	0.011223613
65	0	0	0	0.011628213
125	0	0	0	0.012965634
74	0	0	0	0.014940862
338	0	0	0	0.015299018
374	0	0	0	0.01540493
75	0	0	0	0.017594922
260	0	0	0	0.017933672
25	0	0	0	0.017934713
271	0	0	0	0.017964031
93	0	0	0	0.018607157
6	0	0	0	0.018933859
180	0	0	0	0.021155876
102	0	0	0	0.021644221
357	0	0	0	0.022416802
218	0	0	0	0.023826498
378	0	0	0	0.024208786
366	0	0	0	0.025530964
154	0	0	0	0.025851298
387	0	0	0	0.029967727
386	0	0	0	0.036579213
97	0	0	0	0.05317293

Table C-12. Relative Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Relative Growth Rate
291	0	0	0	0.107235054
144	0	0	1	-0.00315084
48	0	0	1	0.004697619
344	0	0	1	0.005771687
362	0	0	1	0.011544347
233	0	0	1	0.011627778
67	0	0	1	0.011941373
110	0	0	1	0.012798325
137	0	0	1	0.013038635
83	0	0	1	0.013595475
111	0	0	1	0.014378784
10	0	0	1	0.014497256
168	0	0	1	0.01475705
206	0	0	1	0.015698825
245	0	0	1	0.015867652
356	0	0	1	0.01587938
92	0	0	1	0.016387044
368	0	0	1	0.017483136
108	0	0	1	0.017904509
81	0	0	1	0.017978978
268	0	0	1	0.019192749
113	0	0	1	0.019634206
52	0	0	1	0.019663171
69	0	0	1	0.019728117
253	0	0	1	0.019863056
250	0	0	1	0.019925628
156	0	0	1	0.020200879
2	0	0	1	0.020388186
33	0	0	1	0.021217039
118	0	0	1	0.022033479
54	0	0	1	0.022486255
70	0	0	1	0.022636726
152	0	0	1	0.023273284
175	0	0	1	0.025737767
183	0	0	1	0.026527625
9	0	0	1	0.026981593

Table C-12. Relative Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Relative Growth Rate
130	0	0	1	0.027606044
47	0	0	1	0.028572997
264	0	0	1	0.030644321
140	0	0	1	0.035467011
217	0	0	1	0.040955303
29	0	0	1	0.043223648
350	0	0	1	0.067774236
44	0	0	1	0.156796004
585	0	1	0	-0.03477505
562	0	1	0	-0.00375310
577	0	1	0	-0.00133966
521	0	1	0	-0.00114885
505	0	1	0	-0.00046699
586	0	1	0	0
423	0	1	0	0.000229163
548	0	1	0	0.000239464
422	0	1	0	0.000335028
437	0	1	0	0.001715329
570	0	1	0	0.01121953
561	0	1	0	0.01162058
572	0	1	0	0.01315087
615	0	1	0	0.033921338
121	0	1	1	0.004054917
224	0	1	1	0.008962977
200	0	1	1	0.015365581
17	0	1	1	0.020309038
208	0	1	1	0.021913691
774	1	0	0	0.027181378
132	1	0	0	0.030868669
182	1	0	0	0.033910941
364	1	0	0	0.036714262
19	1	0	0	0.037792708
279	1	0	0	0.039399745
390	1	0	0	0.039499108
780	1	0	0	0.039953581
55	1	0	0	0.040182151

Table C-12. Relative Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Relative Growth Rate
324	1	0	0	0.040591043
86	1	0	0	0.041065935
242	1	0	0	0.041984996
226	1	0	0	0.042052145
309	1	0	0	0.04381607
395	1	0	0	0.044355051
792	1	0	0	0.048236284
781	1	0	0	0.048510023
777	1	0	0	0.048590625
304	1	0	0	0.050477058
771	1	0	0	0.051684503
379	1	0	0	0.054231705
239	1	0	0	0.054448621
837	1	0	0	0.055190265
802	1	0	0	0.055536126
256	1	0	0	0.058595588
219	1	0	0	0.0590825
167	1	0	0	0.06701738
62	1	0	0	0.067149455
285	1	0	0	0.067221621
820	1	0	0	0.067898486
129	1	0	0	0.076284728
836	1	0	0	0.076536118
257	1	0	0	0.077491757
381	1	0	1	-0.00316857
171	1	0	1	0.015379972
351	1	0	1	0.015503148
91	1	0	1	0.02476445
38	1	0	1	0.026465551
332	1	0	1	0.033560846
192	1	0	1	0.036244391
305	1	0	1	0.037227249
307	1	0	1	0.037747588
294	1	0	1	0.03864001
269	1	0	1	0.041828757
162	1	0	1	0.042401438

Table C-12. Relative Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Relative Growth Rate
107	1	0	1	0.043968178
784	1	0	1	0.044166091
12	1	0	1	0.044423947
119	1	0	1	0.045295748
787	1	0	1	0.045924889
157	1	0	1	0.046359331
359	1	0	1	0.047375368
808	1	0	1	0.047451938
227	1	0	1	0.047650058
293	1	0	1	0.047921017
335	1	0	1	0.048242302
131	1	0	1	0.04853931
222	1	0	1	0.049059561
283	1	0	1	0.051526801
793	1	0	1	0.052313587
770	1	0	1	0.05711842
158	1	0	1	0.057648309
328	1	0	1	0.058813233
289	1	0	1	0.06090012
829	1	0	1	0.061625814
385	1	0	1	0.062148178
762	1	0	1	0.065318594
798	1	0	1	0.0663286
255	1	0	1	0.066500146
783	1	0	1	0.067069228
165	1	0	1	0.067217853
773	1	0	1	0.076592227
761	1	0	1	0.08252887
805	1	0	1	0.145713692
657	1	1	0	-0.01092545
406	1	1	0	-0.00098555
435	1	1	0	-5.85E-05
716	1	1	0	0.001017124
580	1	1	0	0.00288006
398	1	1	0	0.003070793
448	1	1	0	0.003144324

Table C-12. Relative Growth Rate Data. Continued

TagNum	Destination	Species	House	30 day Relative Growth Rate
515	1	1	0	0.003210231
573	1	1	0	0.003602488
630	1	1	0	0.007086094
700	1	1	0	0.012499555
713	1	1	0	0.012815399
449	1	1	0	0.01487943
695	1	1	0	0.015024631
691	1	1	0	0.018302829
484	1	1	0	0.018894328
452	1	1	0	0.018980702
483	1	1	0	0.02416385
596	1	1	0	0.041460294
480	1	1	0	0.060752658
647	1	1	1	-0.01486833
517	1	1	1	0.000870777
574	1	1	1	0.002599108
661	1	1	1	0.005729302
525	1	1	1	0.007194691
668	1	1	1	0.007420399
429	1	1	1	0.010438959
671	1	1	1	0.011389163
677	1	1	1	0.014429574
673	1	1	1	0.01497137
462	1	1	1	0.017533194
682	1	1	1	0.028411102
488	1	1	1	0.035544674

Table C-13. Relative Growth Rate Summary Statistics

Destination	Species	House	N Obs	Mean	Std Dev	Min	Max
0	0	0	36	0.0189	0.0181	0.0041	0.1072
		1	43	0.0238	0.0236	-0.0032	0.1568
	1	0	14	0.0022	0.0145	-0.0348	0.0339
		1	5	0.0141	0.0076	0.0041	0.0219
1	0	0	33	0.0504	0.0135	0.0272	0.0775
		1	41	0.0501	0.0226	-0.0032	0.1457
	1	0	20	0.0125	0.0161	-0.0109	0.0608
		1	14	0.0111	0.0120	-0.0149	0.0355

Table C-14. Type III Tests of Fixed Effects for Relative Growth Rate, Full Model

Effect	Num DF	Den DF	F Value	Pr > F
Destination	1	95.44	13.75	0.0004
Species	1	35.84	54.74	<.0001
Destination*Species	1	35.84	56.30	<.0001
House	1	86.61	30.42	<.0001
Destination*House	1	86.61	23.67	<.0001
Species*House	1	86.61	45.36	<.0001
Destination*Species*House	1	86.61	2.63	0.1086

Num DF: Demoninator degrees of freedom
Den DF: Numerator degrees of freedom
Pr > F (p-value < α, α = 0.05)

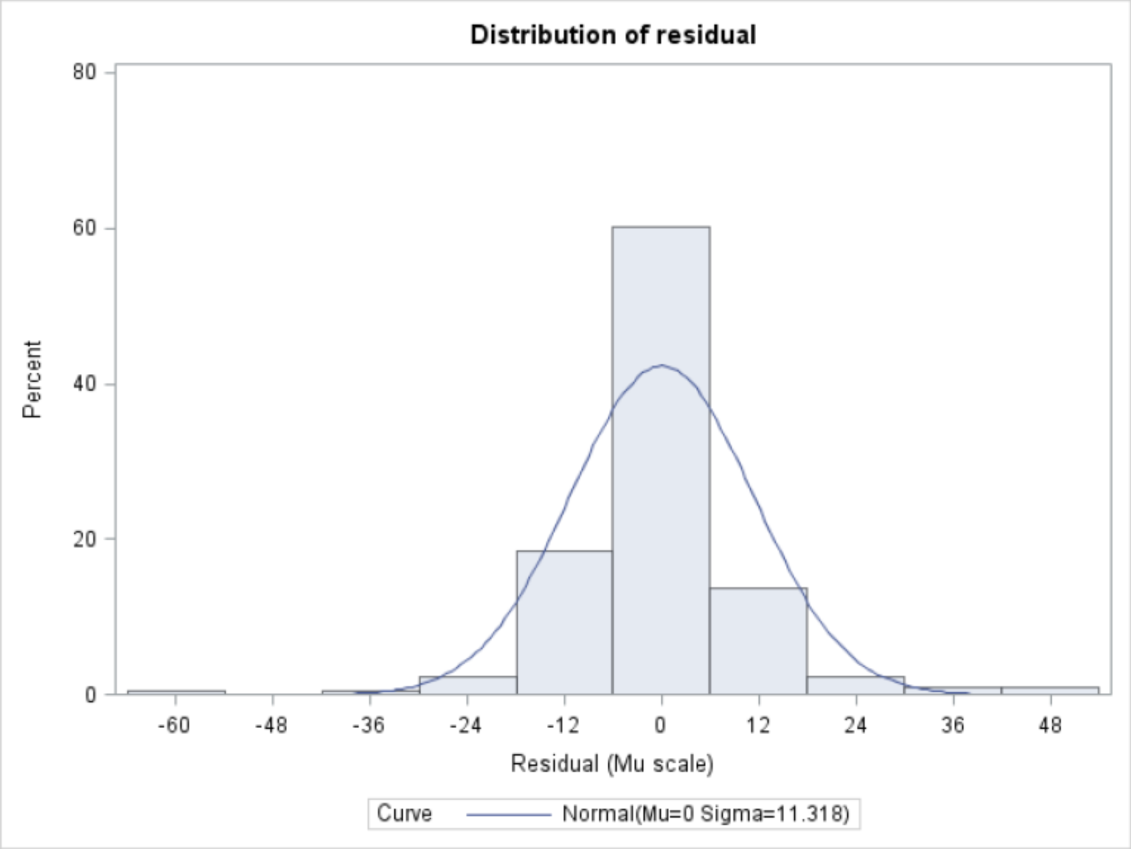


Figure C-10. Conditional Residuals for Rank Relative Growth Rate, Full Model

Table C-15. Full RGR_{30} Model Assumptions are Met

*** Diagnostic Summary ***
No severe outliers or influential points found
Normality might be an issue, KS>0.10
Equal variance should be satisfactory

Table C-16. Mean Separation for Rank Relative GrowthRate, Effect=Species, Full RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Species	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
3	0	127.57	4.4422	127.57	4.4422	A
4	1	87.9758	6.1643	87.9758	6.1643	B

Table C-17. Mean Separation for Rank Relative Growth Rate, Effect=House, Full RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
9	0	99.0399	4.7288	99.0399	4.7288	B
10	1	116.50	5.1055	116.50	5.1055	A

Table C-18. Mean Separation for Rank Relative GrowthRate, Effect=Destination*Species, Full RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Destination	Species	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
5	0	0	90.2147	6.2014	90.2147	6.2014	B
6	0	1	90.7732	9.4744	90.7732	9.4744	B
7	1	0	164.92	6.3619	164.92	6.3619	A
8	1	1	85.1783	7.8888	85.1783	7.8888	B

Table C-19. Mean Separation for Rank Relative GrowthRate, Effect=Destination*House, Full RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Destination	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
11	0	0	74.0607	6.8011	74.0607	6.8011	B
12	0	1	106.93	7.7387	106.93	7.7387	A
13	1	0	124.02	6.5720	124.02	6.5720	A
14	1	1	126.08	6.6617	126.08	6.6617	A

Table C-20. Mean Separation for Rank Relative GrowthRate, Effect=Species*House, Full RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Species	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
15	0	0	129.50	4.7132	129.50	4.7132	A
16	0	1	125.64	4.5778	125.64	4.5778	AB
17	1	0	68.5816	6.1372	68.5816	6.1372	C
18	1	1	107.37	7.3945	107.37	7.3945	B

Table C-21. Tests for Normality, *L. fasciola* RGR_{30} Model

Test	Statistic		p Value	
Shapiro-Wilk	W	0.898434	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.135277	Pr > D	<0.0100
Cramer-won Mises	W-Sq	0.831577	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	4.952349	Pr > A-Sq	<0.0050

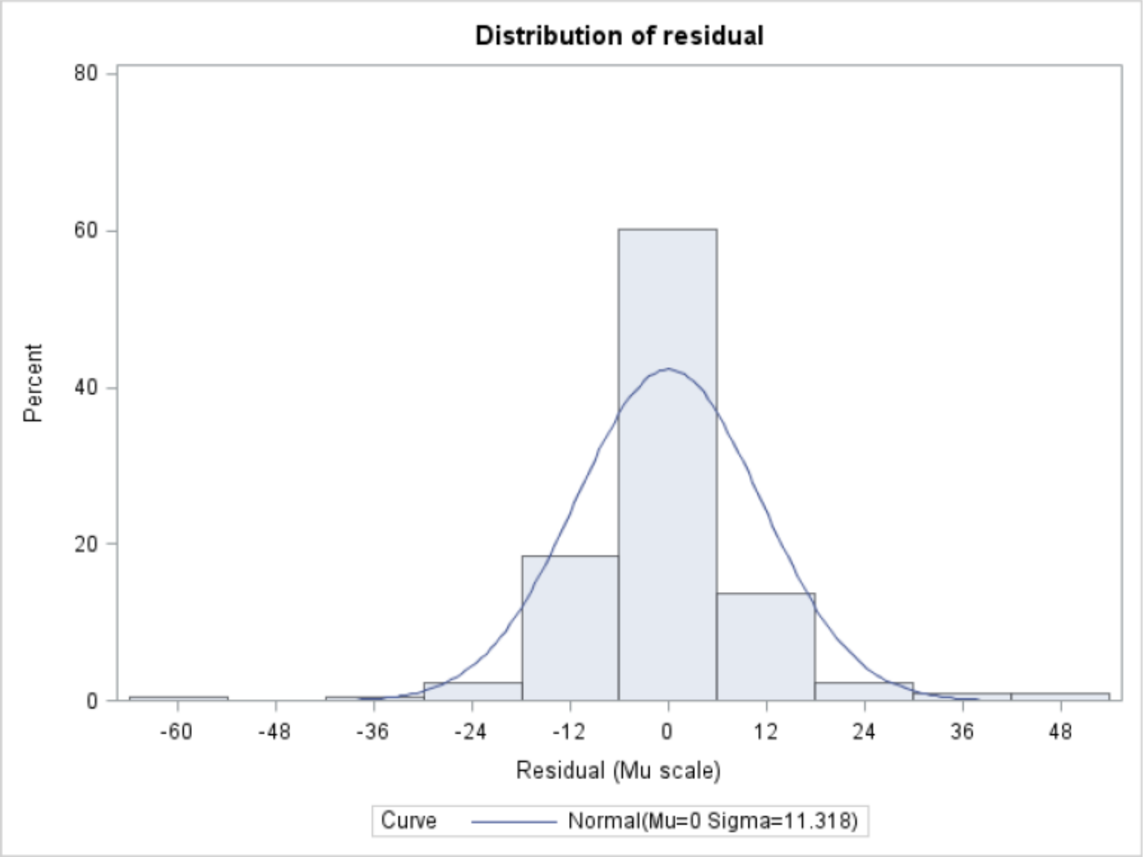


Figure C-11. Residuals for Rank Relative Growth Rate, *L. fasciola* RGR_{30} Model

Table C-22. Type III Tests of Fixed Effects for *L. fasciola* RGR_{30} Model

Effect	Num DF	Den DF	F Value	Pr > F
Destination	1	79.11	83.82	<.0001
House	1	65.49	4.68	0.0342
Destination*House	1	65.49	14.51	0.0003

Table C-23. Mean Separation for Rank Relative Growth Rate, Effect=Destination, *L. fasciola* RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Destina-tion	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
1	0	-	50.0893	4.8539	50.0893	4.8539	B
2	1	-	113.75	4.9789	113.75	4.9789	A

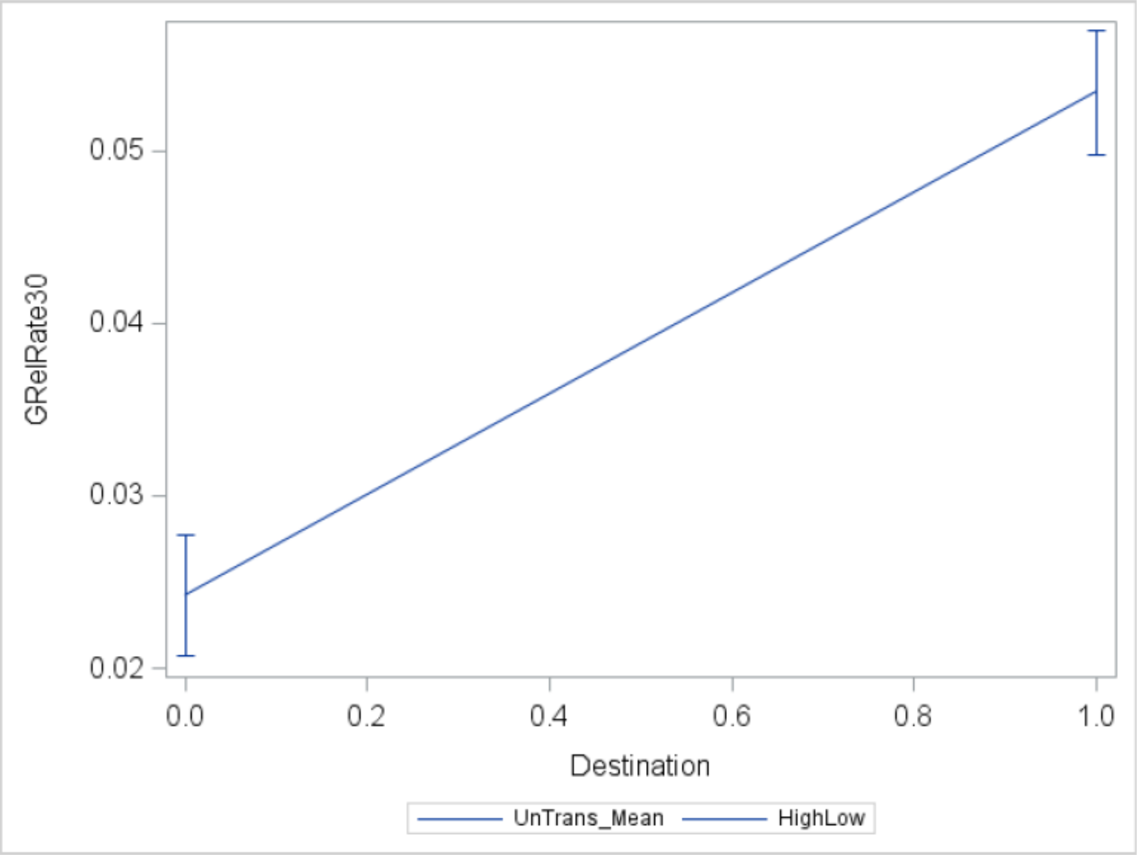


Figure C-12. Destination effect on *L. fasciola* RGR_{30}, Least Squared Means

Table C-24. Mean Separation for Rank Relative Growth Rate, Effect=Destination*House, *L. fasciola* RGR$_{30}$ Model

Method=Bonferroni(P<0.05)

Obs	Destina-tion	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
5	0	0	48.4112	5.1153	48.4112	5.1153	C
6	0	1	51.7674	4.9936	51.7674	4.9936	C
7	1	0	119.84	5.2689	119.84	5.2689	A
8	1	1	107.66	5.1140	107.66	5.1140	B

Table C-25. *M. conradicus* RGR$_{30}$ Model Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	W	0.951572	Pr < W	0.0315
Kolmogorov-Smirnov	D	0.135155	Pr > D	0.0169
Cramer-won Mises	W-Sq	0.155378	Pr > W-Sq	0.0206
Anderson-Darling	A-Sq	0.93129	Pr > A-Sq	0.0183

Table C-26. *M. conradicus* RGR$_{30}$ Model Assumptions are Met

*** Diagnostic Summary ***
No severe outliers or influential points found
Normality might be an issue, KS>0.10
Equal variance should be satisfactory

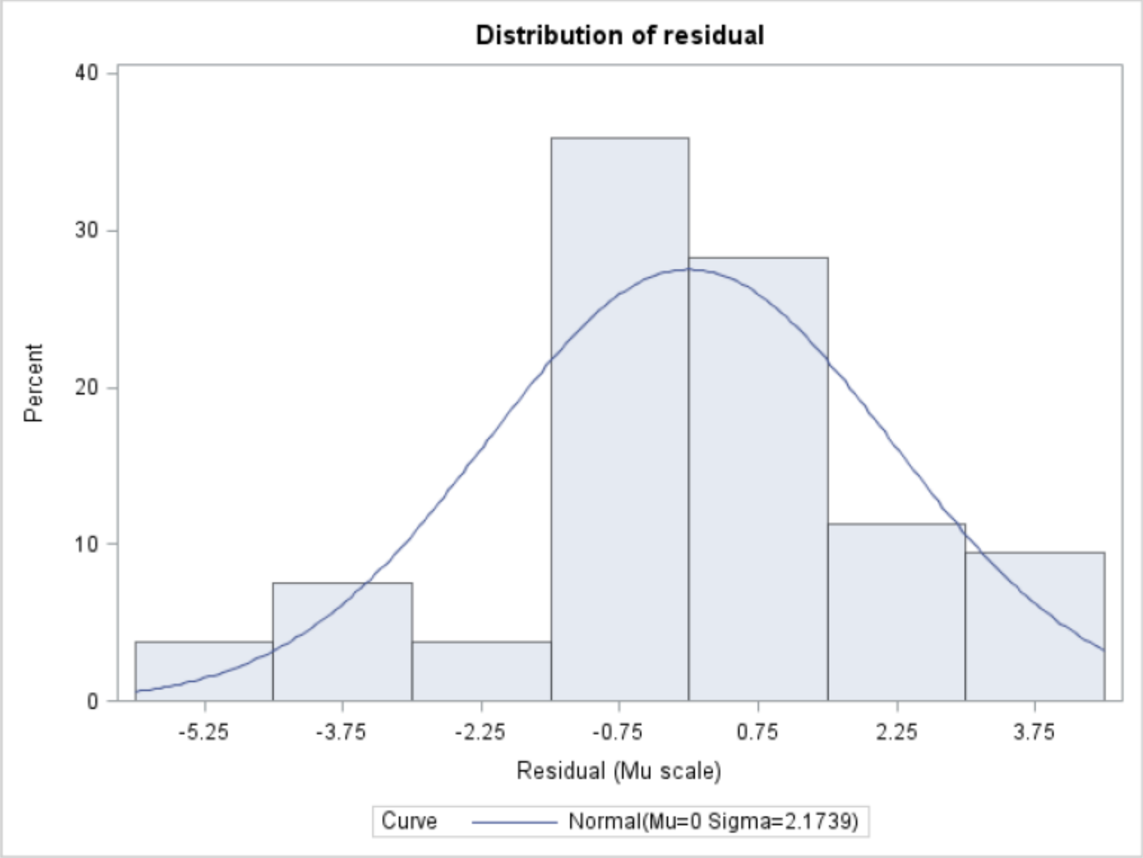


Figure C-13. Residuals for Rank Relative Growth Rate Model for *M. conradicus*

Table C-27. Type III Tests of Fixed Effects for *M. conradicus* Relative Growth Rate

Effect	Num DF	Den DF	F Value	Pr > F
Destination	1	32.83	0.04	0.8399
House	1	17.08	218.37	<.0001
Destination*House	1	17.08	75.92	<.0001

Table C-28. Mean Separation for Rank Relative Growth Rate, Effect=Destination, *M. conradicus* RGR_{30} Model

Method=Bonferroni(P<0.05)

Obs	Destina-tion	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
1	0	-	32.4144	4.2005	32.4144	4.2005	A
2	1	-	33.5212	3.4495	33.5212	3.4495	A

Table C-29. Mean Separation for Rank Relative Growth Rate, Effect=House, *M. conradicus* RGR$_{30}$ Model

Method=Bonferroni(P<0.05)

Obs	Destina-tion	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
3	-	0	23.0464	2.7097	23.0464	2.7097	B
4	-	1	42.8891	2.8863	42.8891	2.8863	A

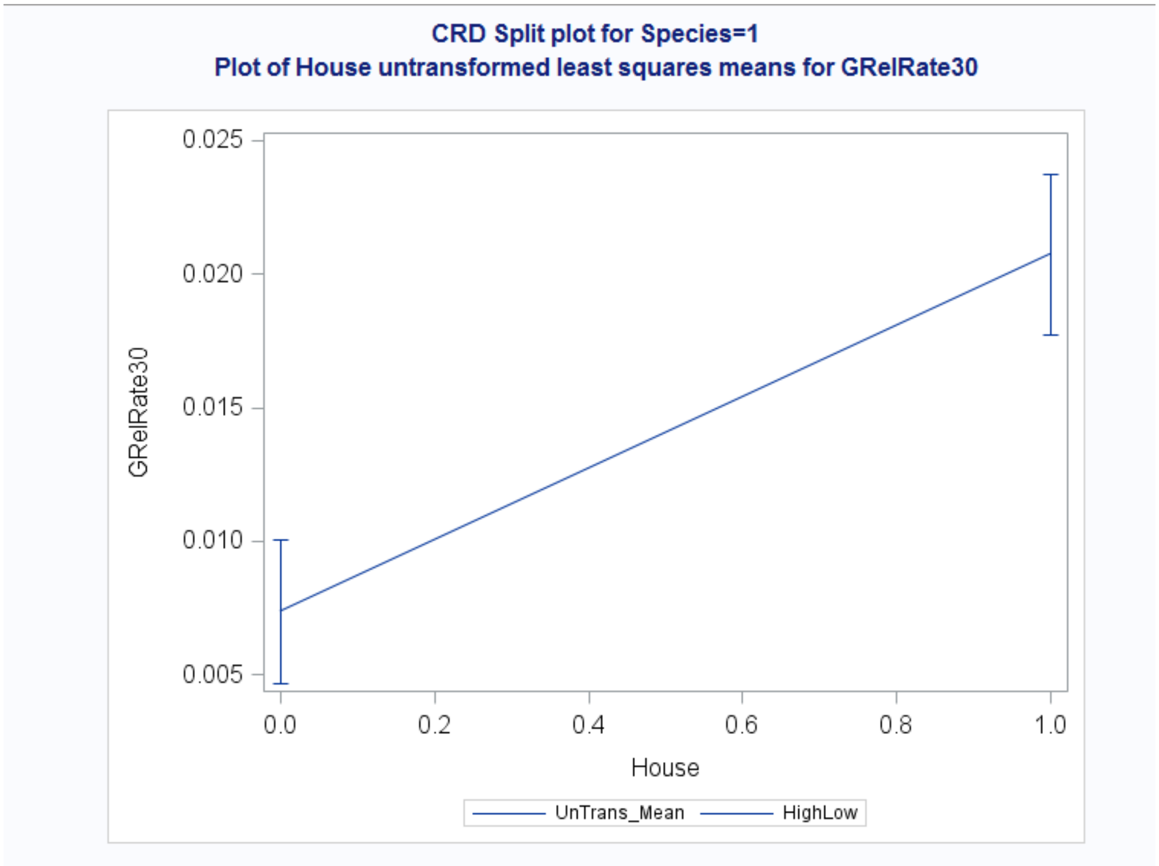


Figure C-14. House effect on *M. conradicus* RGR$_{30}$, Least Squared Means

Table C-30. Mean Separation for Rank Relative Growth Rate, Effect=Destination*House, *M. conradicus* RGR$_{30}$ Model

Method=Bonferroni(P<0.05)

Obs	Destina-tion	House	Estimate	Standard Error	Mean	Standard Error of Mean	Letter Group
5	0	0	16.6429	4.1564	16.6429	4.1564	B
6	0	1	48.1859	4.5459	48.1859	4.5459	A
7	1	0	29.4500	3.4775	29.4500	3.4775	B
8	1	1	37.5923	3.5578	37.5923	3.5578	A

VITA

Laura Pullum was born in Oak Ridge, TN, graduating from Oak Ridge High School. As a child she enjoyed school, sports and playing in the creek behind her parents' house finding parts of crinoids and other invertebrate fossils. She went to undergraduate school on a basketball scholarship. Laura earned a BS in Mathematics and a Masters in Operations Research from the University of Alabama in Huntsville. She subsequently earned an MBA and a Doctorate in Systems Engineering from the Southeastern Institute of Technology in Huntsville.

She is an amateur paleontologist with membership in the Florida Paleontological Society and hundreds of hours of field experience. Given this interest, Laura recently earned a Masters in Geology from the University of Tennessee. Each of her graduate degrees was earned while working full time.

Laura is a senior research scientist in the Computational Data Analytics Group at Oak Ridge National Laboratory, with over 30 years experience. Prior to joining ORNL, she worked in industry, at a non-profit research institute, as a visiting professor, and as a small business owner. Her current research includes evaluation, verification and validation (V&V) of predictive analytics and machine learning systems, and the use and V&V of machine learning approaches for the examination of disease dynamics. She serves as the systems lead on the National Institute of Mathematical and Biological Synthesis (NIMBioS) working group on Modeling Antimicrobial Resistance Intervention, noted in the *National Action Plan for Combating Antibiotic-resistant Bacteria* developed in response to Executive Order 13676.

Dr. Pullum has authored numerous publications including books, book chapters, and peer-reviewed papers; holds one patent, serves on technical advisory boards and NSF review panels, and serves on the standards working group for the IEEE

Standard for System Verification and Validation. She is a senior member of the IEEE Computer Society.