Implementing American Eel Passage on Existing Dams

Kenneth W. Able
able@marine.rutgers.edu
609-296-5260 x230

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Executive Summary

The decline of the American eel (*Anguilla rostrata*) in recent decades has prompted concern for the status of this species. One of the principle factors affecting this species is dams which prevent glass eels and elvers from moving up into many freshwater habitats including numerous tributary creeks to Barnegat Bay. In this two year study we evaluated variation in glass eel supply to Barnegat Bay (through Little Egg Inlet) and to dams at three creeks (Kettle, Mill, and Tuckerton creeks) from the northern to the southern extent of the bay and communicated our findings in a variety of ways.

The supply of glass eels to the bay occurred in winter through late spring but the supply to individual watersheds varied dramatically. In both years the greatest number of glass eels occurred at the dam at Tuckerton Creek, the closest location to Little Egg Inlet. Markedly fewer were collected at the dam on Kettle Creek and there were virtually none at the dam at Mill Creek. Kettle Creek was the most distant from an inlet to the ocean and this may account for the reduced catches. It is not clear why glass eels were so rare at the dam at Mill Creek except that glass eel migration upstream may have been confounded by a large lagoon development between the bay and the dam. The lagoon development consisted of numerous dead end canals. The numerous sources of freshwater drainage from the lagoon edges may have compromised the ability of the eels to follow cues from natural waters upstream. Given the variation observed at the various dams any future attempt to increase eel passage at dams should determine if a glass eel supply exists. The role of watershed modifications that may confound cues to upstream habitat should also be considered.

Passive passage of glass eels over dams can be accomplished by providing consistent, relatively low flow from above a dam over a substrate (mesh from old trawls or burlap) through a pipe that matches the individual contours of the numerous types of dams in the bay watershed. These efforts to pass eels in the bay should be focused from January through May based on the seasonality of glass eels in this and earlier studies. Future efforts should focus on determining the carrying capacity and trophic interactions of eels in lakes and watersheds once they pass above dams and their ability to pass downstream over dams as they start to reproductively mature into silver eels.

Introduction

The recent decline of the American eel (*Anguilla rostrata*) in North America is a cause for immediate concern among fishermen, fishery scientists, and managers (Haro et al. 2000). These downward trends in abundance (both anecdotal and confirmed) appear to be occurring over large spatial scales (e.g. Lake Ontario, New Brunswick, Prince Edward Island, New York, Virginia; Richkus and Whalen 2000) and mirror declines in catadromous eel populations world-wide (*Anguilla anguilla, Anguilla japonica;* Dekker 2003, Tatsukawa 2003). A number of hypotheses have been suggested to explain these observed patterns: over-fishing of pre-spawning stages (i.e. estuarine residents; McCleave 1996), changes in the strength / position of major current systems (Castonguay et al. 1994a, b; Wirth and Bernatchez 2003), and habitat loss (Busch et al. 1998), including that due to dams both along the east coast (Busch et al. 1998, Greene et al. 2009, Bourne et. al 2011) and in New Jersey (Durkas 1992). Of these, the passage by glass eels and elvers to upstream areas above dams is most likely to have a positive impact. Thus, this project addresses the Barnegat Bay Partnership (BBP) strategic objectives on Habitat Loss and Habitat Restoration.

Glass eel and elver stages of the American eel are known to congregate at the base of dams in various Barnegat Bay watersheds during their upstream migration during the winter – early spring, as our previous research has clearly shown for adjacent estuaries (Sullivan et al. 2006, 2009). For the purposes of this report, glass eel pigmentation is identified in seven stages after Haro and Krueger, 1988 and the term "elver" refers to a fully pigmented individual. These dams present a barrier to the migration of this species to upstream freshwater habitat. The original goal of the project was to provide passage for the American eel (glass eels and elvers) over dams in Barnegat Bay utilizing low technology methods. Evaluation of the efficiency of the various techniques to be used can result in the selection of the optimal technique for use at other dams in the Barnegat Bay watershed. More specifically, we evaluated glass eel supply to Barnegat Bay (at Little Egg Inlet), determined glass eel and elver abundance above and below each dam, and devised and tested eel passage devices in the laboratory and in the field during 2011 and 2012.

Materials and Methods

Eel Supply to Barnegat Bay

Larval fish were sampled weekly on night flood tides with plankton nets (1 m diameter mouth, 1.0 mm mesh, 3, thirty minute tows on each date) suspended behind Little Egg Inlet (Little Sheepshead Creek) in southern Barnegat Bay (Fig. 1). This night time sampling has occurred over the past 20+ years (e.g. Sullivan et al. 2006, 2009; Able and Fahay 2010) to determine the species composition and seasonal and annual variation in abundance. From this we determined the typical temporal ingress of glass eels into Little Egg Inlet and Barnegat Bay.

Eel Supply to Dam Sites

Eel collectors (Fig. 2), passive structures constructed out of buoyant tufts of unraveled polyethylene rope fiber (Silberschneider et al. 2001, Sullivan et al. 2009), were utilized to collect glass eels and elvers below each dam (Table 2). Each eel collector was constructed by cutting sixty centimeter lengths of polyethylene rope and unraveling these down to singular strands to create one eel collector "tuft". Fifteen "tufts" made up the whole of the collector, which were fastened to a plastic plant holder and then secured to a clay pot bottom to act as a weight. Each collector required approximately 40 hours of effort to construct.

Frequency of sampling with collectors occurred at least 2 times per week at each of three dams (see Table 2). The collectors were deployed at least 24 hours before eels were sampled. The collectors were cleaned with a hose at least once per week before redeployment. For each sample, collectors were pulled and placed in a tub of water where they were dunked 30 times to shake eels from the collector. The tub of water was then poured through a sieve. If eels were found in the sieve then the collector was rinsed a second time. Eels were counted and then a subset was saved for measurement and staging and transported back to the Rutgers University Marine Field Station (RUMFS). Any eels not included as part of the subset were released on site. All eels collected were counted and released on site, except for a subsample (ten eels or 10% of the number of eels collected at the given site, with a maximum number of 40 eels) which was used to determine pigmentation staging and length of eels. The subsample was released after staging and length data was recorded.

Eels collected from passage devices and collectors were measured in millimeters using standard measuring boards. Pigmentation staging and length of a subset of eels (glass, elver) occurred at RUMFS; eels were anesthetized using the drug Tricaine Methanesulfonate (MS-222), measured, and pigmentation stage was determined via microscope. A subset of eels from Kettle Creek and Tuckerton Creek were brought back and measured for condition during June and July, 2011. Eels were dessicated in a drying oven at 70ºC for 48 hours to determine dry weight. Condition was measured as a relative ratio of glass eel dry weight (DW) to wet weight (WW) where relative condition (RC; unitless) is equal to (actual DW-predicted DW)/(predicted DW), (Wuenschel and Able 2008). Physical characteristics (depth, surface temperature, salinity, and dissolved oxygen are recorded with a hand-held YSI) at each dam site were recorded to help determine differences between sites as well as any differences in success of eel collection and passage. Each site, and congruently, each dam face differed (in both dam structure and eel abundance) from the other sites (Fig. 1, Table 1).

<u>Laboratory Observations of Eel Passage Devices</u>

Several laboratory experiments were set up at RUMFS to help determine eel behavior and response to passage devices. Two "dams" were constructed in the lab, the first a singular dam face (30.5 cm x 94 cm) made of aged 1.3 cm plywood. Aged PVC pipe of the same diameter utilized in the field was fixed to the dam face and lined with trawl mesh. A net (1 mm mesh) was fixed to the "upstream" end of the ladder. Two tanks filled with lake water from Lake Pohatcong (water body above the Tuckerton Creek dam), Tuckerton, NJ were staggered and a closed system was installed to have water flowing from the above tank (upstream) to the lower tank (habitat below a dam face). Water from the lower tank was pumped back to the upper tank to allow for continuous flow. This arrangement was also used for the second "dam face" that was constructed, made of new plywood (0.6 m x 2.4 m). The second dam had three lanes (17.8 cm each) which would allow for simultaneous testing of each type of passage device described below. These preliminary experiments (Table 3) used eels from below the dam at Tuckerton Creek and compared preference of passage device, preferences of passing in light or dark, material (aged or new), and time required to pass over each device. Results of these experiments helped in the construction of devices to be implemented in the field.

Field Observations of Eel Passage Devices

In 2011, eel passage devices were placed on the face of the dam spillway at Tuckerton and Kettle creeks, and if needed, stabilized with anchored lines. There were three different design methods: The first device utilized was sewn burlap bags that were simply laid across the dam face. The second device used was white PVC (7.6 cm) piping filled with soil erosion matting. The third was similar PVC piping filled with aged trawl mesh (shrimp trawls from Memphis Net and Twine: 16' width, 1.5" body netting mesh, 1.25" bag netting mesh). In both the PVC and burlap bag approaches, the design serves to reduce water velocity and provide the textured surface needed by the glass eels and elvers to climb up the dam face to gain access to upstream habitat. On all eel passage devices a small mesh (1 mm) net collection system was installed on the upstream end to allow for a count of the number of eels utilizing each passage device and, subsequently, the determination of size and pigmentation stage on a subsample of total eels collected. Any sub-sampled eels collected were transported back to RUMFS so they could be measured and staged. Once this data was collected the sub-sampled eels were released at the collection site.

In 2012, eel passage design was changed to better control the flow within the device in addition to creating a deeper collection bucket to quantify any passing eels. The device was built out of (10.2 cm diameter) corrugated pipe. Because this piping was more flexible it allowed more maneuverability to position and secure the passage devices at Tuckerton Creek and Kettle Creek compared to the PVC pipe from the prior year. The piping was filled with aged trawl mesh based on last year's laboratory and field tests showing trawl mesh was the most utilized material by glass eels. Another change in design was to improve the collection unit on the upstream end of the passage device. In 2011, a plankton net was secured over the end of the passage device, but did not successfully trap eels to be quantified. As a result, the 2012 design was made of a 43.2 cm deep x 55.9 cm wide tub that was fashioned as a live box for eel retention. The live box was partially submerged at the surface and kept afloat by foam wrapped around its top (Fig. 3). The passage device's upstream end was secured inside the tub so eels passing over would swim into the live box to be quantified. This live box was hooked to two standing PVC pipes for stabilization (Fig. 3). At Tuckerton Creek, the pipe that extended below Route 9 was suspended by ropes to allow consistent flow within the device; at Kettle Creek the pipe was laid between rocks on the dam face. The angle of the Kettle Creek dam provided consistent flow within the passage device. Both passage devices at Tuckerton Creek and Kettle Creek had similar flow rate (measured in liters per minute).

Results and Discussion

Eel Supply to Barnegat Bay

Temporal ingress of *Anguilla* glass eels in a typical year (e.g. 2009) through Little Egg Inlet occurs from January through June with highest values in February and much reduced abundance by late April (Fig 4). This pattern is supported by a similar pattern from 1989-2007 (Sullivan et al. 2006, 2009, Able and Fahay 2010). Little Egg Inlet is presumed to be representative of the southern portion of Barnegat Bay; the only two other major sources are Barnegat Inlet and Point Pleasant Canal to the north.

Eel Supply to Barnegat Bay Tributaries

Spatial variation in glass eel supply

The high degree of variation in abundance of glass eels at the Tuckerton Creek dam site is probably due to several reasons. The large collection in both years probably reflects the proximity to Little Egg Inlet, which is a major source of glass eels (Sullivan et al. 2006, 2009; Able and Fahay, 2010). The 2011 supply of glass eels to each dam site also varied over the course of sampling. Glass eels were most abundant in Tuckerton (n=63.7 per collector/per day). Smaller numbers were found at Kettle Creek (n= 11.9 per collector/per day); but none were found at Mill Creek (n=0 per collector/per day) (Figure 5).

The reason for the absence of glass eels at the dam in Mill Creek remains perplexing. Efforts to identify blockages or restrictions within the creek below the dam were made by exploring the creek on three separate dates (June 30, July 13, and July 22, 2011) for a total of 11 hours of effort by several individuals. Initial exploration was done by kayak on June 30, 2011 starting at Mill Creek Park in the Beach Haven West lagoon community. Kayaks followed Mill Creek upstream out of the lagoon development. It was observed that the community was lined with bulkhead and street sewage drains that emptied directly into the creek. Upstream of the lagoon development the vegetation surrounding the creek was more riparian and the creek narrowed considerably. No obvious physical blockages could be found to stop glass eel migration upstream. A few elvers (n=3) but no glass eels were found further upstream at the culvert, which allows Mill Creek to pass under Route 9 and Route 72 in Manahawkin. This sampling effort with dip nets occurred on foot and by water raft. The culvert had beds of long grasses and detritus and was relatively shallow. No obstructions could be seen that would prevent migration of glass eels upstream. Three elvers were caught using dip nets in the grass beds along the banks. The absence of glass eels might be explained by this relatively late effort in the season, when glass eels may have already transformed into elvers and become more difficult to collect. Further analysis of water temperature, salinity, and possibly chemical testing could be done to determine what effects the lagoon development may have on glass eel ingress.

The 2012 glass eel supply also varied between sampling sites. Each site had higher abundance of glass eels compared to the 2011 season. The total glass eel amount in 2011 from all three sites yielded 5,903 glass eels, whereas the net amount of eels from all sites in 2012 nearly quintupled to 25,054 glass eels. The observed early ingress of eels from 2012 compared to 2011 could be due warm weather conditions over the past winter, but no real determination can be made. Reasons for the large number of eels caught in 2012 were more likely due to an earlier start in the season. Other possibilities include the use of newly made eel collectors, which were denser than the older eel collectors and may have perhaps caught more eels as a result, or perhaps a larger abundance of eels ingressing during the 2012 season.

The low supply of glass eels to the dam at Mill Creek in 2011 was also addressed in 2012. The new eel collectors were originally constructed for the use of sampling sites (Fig. 1B) along Mill Creek in an effort to determine if glass eels were in fact entering that particular system. Five sites were determined starting at the mouth of Mill Creek in Barnegat Bay and leading up to the dam face (Fig. 1B). Sites were chosen based on what would be thought to be possible eel habitat (sandy shorelines with grassy vegetation). However, most sites were very sandy and shallow and in some cases (e.g. the mouth of mill creek) the only place deep enough to deploy a collector was far from vegetation considered to be habitat for glass eels to hide in.

The result of the initial sampling (January 20 & February 9, 2012) at the Mill Creek sites was that no glass eels were found. Observation therefore returned to the Mill Creek dam face. The dam itself has two large holes in the cement at the base of the dam face, causing water from the lake to shoot out and create two eddies below the dam. These eddies create a potentially confusing back-current for eels – in other words while the current should be moving away from the bottom of the dam, it is instead moving toward the dam face. Glass eels are positively rheotactic, therefore want to swim against the current heading upstream as opposed to with a current. This could have been one of the reasons why no glass eels were caught so close to the dam face at Mill Creek. Another observation made was at the part of the creek (nearest the dam face) where the current did flow the correct way - downstream; in 2011 this part of the creek was dry – the shallow depth left much of the creek dry, sandy, and exposed. However, in 2012 the part that was usually dry was now covered with water. Although shallow, it was just deep enough to mostly submerge an eel collector. Eel collectors were deployed (February 16 – April 13, 2012) at this new location a little further downstream from the dam face and after 24 hours, a few glass eels were found in the collectors on multiple occasions (February 17 (n=2), February 21 (n=1), and February 24 n=(8)). To make sure that this pattern was a reflection of the new location in which we sampled, collectors were also deployed simultaneously at the face of the dam as in 2011. No eels were caught there throughout the season.

Temporal variation in glass eel supply

The 2011 increase in glass eels at the dams in Tuckerton Creek and Kettle Creek, after initial sampling in early March, implies that we sampled them shortly after their arrival at these upstream sites (Fig. 5A). The peak in occurrence at Kettle Creek (which had lower numbers than Tuckerton Creek) was not until mid-April, while high numbers persisted at Tuckerton Creek from approximately mid-March through mid-April. This suggested a relatively later arrival time at Kettle Creek, perhaps due to a greater distance from a source at one of the inlets (Fig. 1) unless the Point Pleasant Canal serves as a source from the Manasquan Inlet and River. Sampling at the dam sites started during the peak for eel recruitment at Little Egg Inlet and continued through the end of July (Fig. 4). This is congruent with the average peak of expected ingress of glass eels. A general decline in the number of glass eels at Tuckerton and Kettle Creek was observed from March to July (Fig. 5A). The highest abundance of glass eels was at Tuckerton, followed by Kettle Creek (Table 2; Fig. 5A).

In 2012, glass eels entered the system by the end of January and beginning of February. As a result, sampling at the dams began earlier than in 2011. The peak of ingress at Tuckerton and Mill Creek occurred during the last week of February and the peak at Kettle Creek occurred during the second week of March (Fig. 5B, 5C). This peak in ingress occurred earlier at all sites compared to the previous year. Tuckerton Creek yielded the highest numbers of glass eels (n= 23,913), followed by Kettle Creek (n=1130) and then Mill Creek (n=11). This follows a similar pattern as the previous year's catch per unit effort however 2012 yielded more glass eels in total than in 2011. Eel stages were more advanced later in the period from April through July 2011 with slightly later stages occurring further up the bay at Kettle Creek. The mean stage of development increased (i.e. later in development) at Tuckerton Creek into April and June then declined thereafter (Fig. 6A). The mean stage of glass eels at Kettle Creek was typically higher on many collecting dates than at Tuckerton Creek. In 2012, eel stages changed over the sampling period from January through April, with late stage occurring later in the sampling season. Kettle Creek appeared to have slightly later stage eels than Tuckerton (Fig. 6B). Mean length at Tuckerton (57.0 mm) and Kettle (57.4 mm) creeks was similar across the April through July sampling period in 2011 (Fig. 7A). Mean lengths were also similar during the January through April sampling period in 2012 for all three sites; Tuckerton Creek (56.5 mm), Kettle Creek (57.4 mm), and Mill Creek

(57.7 mm). In addition to these measurements a small sample of eels were measured for condition (Fig. 8). The relative condition of these eels did not change with increasing length at Tuckerton; however, there was a slight correlation between increasing length and relative condition from eels caught below the dam at Kettle Creek. There was no correlation between eel length and stage.

In both the 2011 and 2012 seasons, temperatures between sites were all relatively similar. Average surface and bottom temperatures had negligible difference between them. The surface and bottom salinities varied greatly between Tuckerton and the other two sites (Figures 9A-11D). Tuckerton Creek is much more of an estuarine environment (Table 1) as opposed to the freshwater habitats at Kettle Creek and Mill Creek. This may cause the increased abundance at Tuckerton, although this site is also closest to a source of glass eels at Little Egg Inlet (Fig. 1). Temperatures for March-April were warmer in 2012 than 2011. Temperature data before this was not available from 2011 since eel collection began later that year. Salinities remained relatively similar for all sites between years (See Fig. 9C, 9D, 10C, 10D, 11C, 11D).

Spatial and Temporal variation in elvers

While glass eel ingress decreased over time, the inverse was true of elvers at all sites (Fig. 12A). Over the 2011 sampling period there was a general increase in the number of elvers at each dam site. This is expected to occur as the *Anguilla* metamorphose to the elver stage as they move to upstream habitat in the months past the peak of ingress, a pattern observed in adjacent estuaries (Sullivan, et al. 2006). The highest abundance of elvers was found at Mill Creek (n=66), followed by Kettle (n=32), and Tuckerton creeks (n=18) with a total number of 116 elvers from all sites. The high numbers at the Mill Creek dam are surprising given the absence of glass eels. These high numbers persisted to the end of sampling in July. In 2012, the same observation of increased number of elvers occurred over time. The total number of elvers collected in 2012 was significantly less than the number collected during the 2011 season, perhaps because the sampling was discontinued earlier. A total of 22 elvers were observed during 2012, the highest number being found at Kettle Creek (n=8) and an equal number being found at Tuckerton Creek and Mill Creek (n=7) (see Fig. 12B).

Observations above dams

Observations were made in the lakes above dams to evaluate the evidence for eel passage. Eels were found by seining above the dams at Kettle Creek and Mill Creek, but none were found at Tuckerton during the sampling period of June 2011 to July 2011. However, in a Rutgers University class field session on September 23, 2011 students seined and electro-fished above the dam at Tuckerton Creek in Lake Pohatcong. Using a 30.5 m seine, students caught individuals ranging in length from 190-410 mm (n=5). When electrofishing, eels caught ranged from 75-160 mm (n= 4). It was observed during electro-fishing that a large number of smaller eels were stunned but fell through the dip-net mesh before being quantified. These methods, however, showed a presence of yellow eels above the dam at Tuckerton. Thus, some eels are able to get above the dams but further sampling would be necessary to evaluate the extent of this occurrence. The range of total length of eels caught above Kettle Creek dam was 84-173 mm (n=10; glass eels 1, elvers 9) with an average length of 108.9 mm. At Mill Creek only two elvers were caught, the range in length was 83-87 mm. In 2012 electrofishing was attempted again in Lake Pohatcong (the lake above Tuckerton Creek dam) on April 5, 2012 but was unsuccessful due to generator failure.

Laboratory Observations of Eel Passage

Laboratory experiments were conducted in 2011 when passage of glass eels above the dams was not as successful as anticipated. Small scale dams were therefore constructed in the laboratory to better understand behaviors of the glass eels relative to the use of eel passage materials that might hinder migration success. Results of each of these passage observations had varied eel response (Table 3). Between April 27 and June 5, four sets of glass eels from Tuckerton Creek were used in experiments on either the single lane dam or the three lane dam. What was conclusive was that eels did respond to the freshwater cue over the dam face and eels were able to climb up and over the dam faces. However, these results were not consistent between eels used in each experiment. More specifically, initial experiments on April 27 yielded positive results. Using a 1.3 cm thick 30.5cm x 94cm piece of wood and PVC piping filled with trawl mesh, 50+ eels passed over the small scale dam (33% of total eels available) (Table 3). Another set of experiments using the same dam were started on May 3 and 97+ eels (65%) successfully passed. In a later experiment on May 4 only 6 eels (4%) passed, while on May 5 none passed.

In a subsequent experiment, the design of the ladder was modified; a 3-lane plywood dam was constructed 0.6 m wide by 2.4 m long. This dam allowed 3 ladders (17.8 cm wide each) to be run simultaneously. One ladder was open trawl mesh, the second was PVC piping filled with erosion matting, and the third was PVC pipe filled with trawl mesh (Table 3). From May 11 to May 14 only 3 eels made it over the dam with the open trawl mesh. None successfully made it over the PVC trawl mesh ladder although observations were made of eels on the ladder. No eels were present on the erosion matting or made it over; the erosion matting also had a strong odor and eels appeared to turn away from it altogether. For this reason, we discontinued the use of this material in 2012. By June 1, 2011 use of the original single lane ladder design was set up again. On June 5, 6 eels (24%) passed over into the collector. Experiments run past this date did not pass any eels. This was hypothesized to be due to the fact that many eels were reaching the elver stage and perhaps they were less likely to migrate while emphasizing feeding activities.

Each of the experiments conducted had limiting factors; the experimentation time varied for each, some ranging 24 hrs while other experiments went up to 4 days (Table 3). The amount of eels introduced also varied in each experiment. Some experiments started with 100 eels, but as time went on the number of glass eels diminished with the season and so some experiments started with 25 eels. In addition once a success was made in the lab with eel passage the design was rapidly modified and a new experiment was started. This was in part due to the need to observe behaviors while competing with the window of time we could work with glass eels (before reaching the elver stage) in both the laboratory and the field. It appeared as summer approached both the number of eels diminished as well as their inclination to climb over the dam face.

Eel behavior in the preliminary observations (n= 17 trials) from the laboratory indicated a preference for the trawl mesh for passage, while there was a complete lack of use of the erosion matting. As a result, field passage devices all incorporated the use of trawl mesh enclosed in PVC pipe as the primary experimental material. Other behaviors observed were that in the successful lab experiments eels would drop into a live box from the mouth of the ladder. Several experiments tried the use of a plankton net (n=2) as an upstream device to verify passage, but eels did not successfully pass into this net. In the field, the initial design used (1 m-1 mm) plankton net at the mouth of each ladder above the dams.

Field Observations of Eel Passage

Each dam site presented challenges based on either its construction, height, or other physical characteristics (Table 1) that made it necessary to develop individual passage devices. At the dam at Tuckerton Creek, the long culvert below the dam, which was located under Route 9, had a very strong current and was difficult to access. When the ladder was installed it took multiple efforts to try and reduce the water flow running from the top of the dam to below. The ladder was stuffed with trawl mesh initially; the mesh was fixed onto the PVC pipe, but because the velocity was so strong instead of reducing speed in the ladder, it instead pulled the bunched up trawl mesh taught and made it ineffective for glass eel passage. After blocking part of the opening of the PVC piping water flow was able to be reduced but the issue of the current in the culvert posed problems. It appeared that the high current speed made it very difficult for glass eels to pass the culvert and approach the eel ladder at the base of the dam face; however this issue was not able to be resolved during the 2011 sampling season.

In 2012, this issue was taken into consideration at the start of the glass eel season. The passage device at Tuckerton was re-designed to allow more control of the flow within the device as well as provide a better collection unit on the upstream end. Corrugated plastic piping was used instead of rigid PVC pipe because it was more flexible and could be moved easily under Route 9 (the dam face had severe angles that could not be compensated for with rigid PVC piping). The corrugated pipe allowed us to suspend the device at the appropriate angle to help control flow within the pipe in addition to providing an easier angle of ascent for glass eels (Fig. 3). The upper end of the corrugated pipe was then placed inside a floating tub that acted as a “live box” as opposed to the plankton net that was used unsuccessfully in 2011.

At Kettle Creek the dam face had a slow enough water flow that some eels may have been able to climb the dam face and go upstream. In 2011, the passage device was placed on the dam face and glass eels were observed crawling through the trawl mesh of the device. Because the dam face is “open” unlike at Tuckerton, where the dam extends below Route 9, other ladder prototypes (open trawl mesh, burlap) were set up at Kettle Creek as well to test use of materials. Eels were observed on the trawl mesh although not observed on the burlap bags. To verify successful passage above the dam, a plankton net was fixed to the mouth of the passage device so eels could swim above the dam into the net. No glass eels were observed in the net; one was observed on the net but none could be quantified as “passing above the dam” through our collection device. There was not enough time in the 2011 sampling season to revise our collection unit design.

During 2012, further revisions were made to the Kettle Creek passage device. As at the Tuckerton Creek dam, corrugated piping replaced PVC in addition to installing a similar live box on the upstream end at Kettle Creek. While no eels were quantified during the sampling seasons, glass eels were found in the live box when it was time to break down the device. This suggests that while eels were utilizing the new live box, it was perhaps easy for them to escape before being quantified and therefore further redesign would need to take place in order to quantify passage.

Use of eel collectors, passage devices, and materials are based, in part, on prior attempts to collect (Sullivan et. al 2006) and to provide passage for American eels associated with impoundments in the Delaware Bay watershed (Strait and Shotzberger 2002). In these successful evaluations, hundreds of glass eels and elvers were collected with a PVC pipe lined with discarded trawl mesh when spring temperatures were 13 - 39°C. The 2012 season began earlier than in 2011, and the results yielded a higher number of glass eels that were collected, an improved passage device design, and some success in quantifying eels that made it into a modified live box. Future endeavors would focus on perfecting the collection device to prevent escape before quantification. Other areas to perfect would be to have total control over the flow within the ladder, which can be achieved at low cost with a battery powered pump.

In general, we feel that any material that reduces water flow and provides a substrate for glass eels to crawl up can be used for eel passage. Thus, trawl mesh or loosely woven burlap within a flexible tube with fresh water from an upstream source should be productive. The creeks in which passage occurred in the lab and field supported this interpretation. The greatest difficulty in our observations was providing a means to collect the glass eels that had passed over the dam in order to quantify them. The confounding efforts of controlling water flow in each individual passage device and capturing glass eels above the dam made it difficult to attain consistency at each site.

Volunteer Support and Outreach

Throughout the sampling period volunteer efforts were made in the field alongside RUMFS technicians and other scientists. In 2011, volunteers helped sample eel collectors, seine in lakes above dams, and check passage devices with technicians and also assisted in exploring Mill Creek at Manahawkin. In 2012, volunteers were also integral in constructing new eel collectors. Jacques Cousteau National Estuarine Research Reserve (JC NERR) volunteers contributed 74.75 hours in 2011 and quadrupled that amount to 326 hours in 2012. A total of 400.75 hours were invested by volunteers (18 individuals) for this project.

In addition to the service of volunteers for this project, RUMFS collaborated with JC NERR (Melanie Reding) to present a talk to high school and middle school groups about the American eel and our efforts at the 2011 World Water Monitoring Day, hosted annually at Batsto Historic Village. This event was sponsored by the New Jersey Pinelands Commission and Wharton State Forest. It is actually part of an annual global event coordinated by the Water Environment Federation and the International Water Association. On World Water Monitoring Day people around the globe take time to examine the quality of their watersheds and enter data into an international database in an attempt to create awareness of the importance of protecting our natural resources. RUMFS and JC NERR took part in this event at Batsto Historic Villiage and educated 200+ students in 2011 about the life history of the American eel and our current research efforts to restore them to upstream habitat. In addition, Melanie Reding also gave a presentation at the New Jersey Marine Educators Association annual Teach at the Beach Professional Development workshop (May, 2011). The presentation discussed the history, life cycle, and cultural importance of the American eel and also current ongoing research happening in New Jersey. Teach at the Beach is for formal and informal educators and took place at Long Beach Island Foundation of the Arts and Sciences. In 2012, a presentation was given (by Jen Smith) on the project as a guest speaker for the JC NERR Lunch n' Learn program hosted at the Tuckerton Seaport. Community members attend the Lunch n' Learn programs and are given the opportunity to talk to the guest speaker and ask questions on the given topic. She summarized the purpose and success of the project in a power point lecture and then answered community members' questions on the research and eels.

During the summer of 2011, a summer intern (Joshua Cullen) took part in this project under NSF-REU Research Internships in Ocean Sciences (RIOS) funding. He focused on American eel behavioral ecology, initially starting in the laboratory and then working in the field to assess eel quantities below dams and passage success above dams. During his internship he was able to explore Mill Creek for any mitigating structures that might help explain the small number of glass eels collected at the dam relative to the other sites, determine relative condition of eels, as well as determining correlations between eel length and stage between sites. These results were presented at a poster session at the Rutgers Institute for Marine and Coastal Sciences at a joint session at the end of the summer and available online at the RUMFS website.

In addition to these activities we provided Barnegat Bay Partnership personnel (Jim Vasslides) logistical support for their own glass eel sampling program. The results of this study will be further disseminated to various resource management agencies at the federal (NOAA Restoration Office – Sandy Hook, NJ), state (NJ DEP Bureau of Fisheries, Fish and Wildlife, and regional levels (Tuckerton Town Council, Tuckerton Seaport).

Acknowledgements

We would like to thank numerous technicians at RUMFS that supported this project, especially Jen Smith and Tom Malatesta, and Roland Hagan, who helped in all phases of this study. We would like to thank Carl Alderson from NOAA Restoration Office in Sandy Hook and Ken Strait of Public Service Enterprise group for helpful conversations about eel passage devices. We would also like to thank the Barnegat Bay Partnership and Corporate Wetlands Restoration Partnership for funding as well as the Research Internships in Ocean Sciences (RIOS) National Science Foundation-Research Experiences for Undergraduates internship funding and to Josh Cullen, an intern who helped continue the eel study into the summer, 2011. We would also like to thank the JC NERR volunteers and especially Pat Filardi, Steve Zeck, Tom Siciliano, Tony Bonovolanta, and Betty Lesher for their contributions during both years of this study.

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TABLE 1: Characteristics of the dams/sampling sites for glass eels and elvers in Barnegat Bay, NJ during 2011 and 2012

Location	**Distance from Dam Face to Bay (km)**	**Distance from Dam Face to Little Egg Inlet (km)**	**Distance of Collectors from Dam Face (m)**	**Size of Lake Above Dam (km^2)**	**Tidal**	**Dam Height (m)**	**Depth Range Below Dam (m)**
Tuckerton Creek Dam	4.9	12.8	24	0.49	Yes	2.0	1-2
Mill Creek Dam	7.1	23.2	6.3	1.6	No	3.2	<1
Kettle Creek Dam	5.0	63.2	3.0	3.2	No	6.4	<1

TABLE 2: Eel sampling effort and abundance at each dam site in 2011 (March-July) and 2012 (Jan-April)

Site:	**Total Samples**		**Total eel collectors deployed**		**Total Glass Eels**		**Total Elvers**	
	2011	**2012**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Tuckerton Creek	26	24	78	72	4972	23,913	18	7
Mill Creek	20	24	60	91	0	11	66	7
Kettle Creek	20	24	60	72	930	1130	32	8
Total	66	72	198	235	5903	25,054	116	22

TABLE 3: Glass eel passage over small scale dams in laboratory observations

Observation Number	Date(s)	Passage Material Tested*	Eel Collection Used**	Number of Eels Passed
1	4/28/11	Single Lane PVC-Trawl Mesh	1	50+
2	5/3/11	Single Lane PVC-Trawl Mesh	1	97+
3	5/4/11	Single Lane PVC-Trawl Mesh	1	10+
4	5/5/11	Single Lane PVC-Trawl Mesh	2	0
5	5/6/11	Single Lane PVC-Trawl Mesh	2	1
6	5/10/11	Single Lane PVC-Trawl Mesh	2	0
7	5/11/11	Single Lane PVC-Trawl Mesh	2	0
8	5/11/11	3 Lane (Trawl Mesh, Erosion Matting, PVC-Trawl Mesh)	2	0
9	5/13/11	3 Lane (Trawl Mesh)	2	2
10	5/16/11	3 Lane (Trawl Mesh)	2	1
11	5/20/11	Single Lane PVC-Trawl Mesh	3	0
12	5/24/11	Single Lane PVC-Trawl Mesh	3	0
13	5/30/11	Single Lane PVC-Trawl Mesh	3	7
14	5/31/11	Single Lane PVC-Trawl Mesh	3	14
15	6/1/11	Single Lane PVC-Trawl Mesh	4	0
16	6/2/11	Single Lane PVC-Trawl Mesh	4	1
17	6/5/11	Single Lane PVC-Trawl Mesh	4	6

* The materials used in the laboratory construction of small scale dam and passage devices consisted of either a singular dam face (12”x37”) made of ½” plywood and 3” PVC filled with trawl mesh (Single Lane PVC-Trawl Mesh) or a 3 Lane plywood dam (2ft x 8 ft) with 7” wide lanes. Each of the three lanes had different material to test: erosion matting, 3” PVC filled with Trawl Mesh, and open trawl mesh. Each 3 Lane experiment is denoted by (3 Lane Trawl Mesh, Erosion Matting, PVC-Trawl Mesh). Successful passage of eels using the 3 Lane model was denoted under passage material tested (e.g. 3 Lane Trawl Mesh).

** Four different collections of eels were used in laboratory experiments. Each collection is denoted (1-4). Glass eel sample size varied for each collection: 1 (n~150), 2 (n~55), 3 (n~190), 4 (n~25).

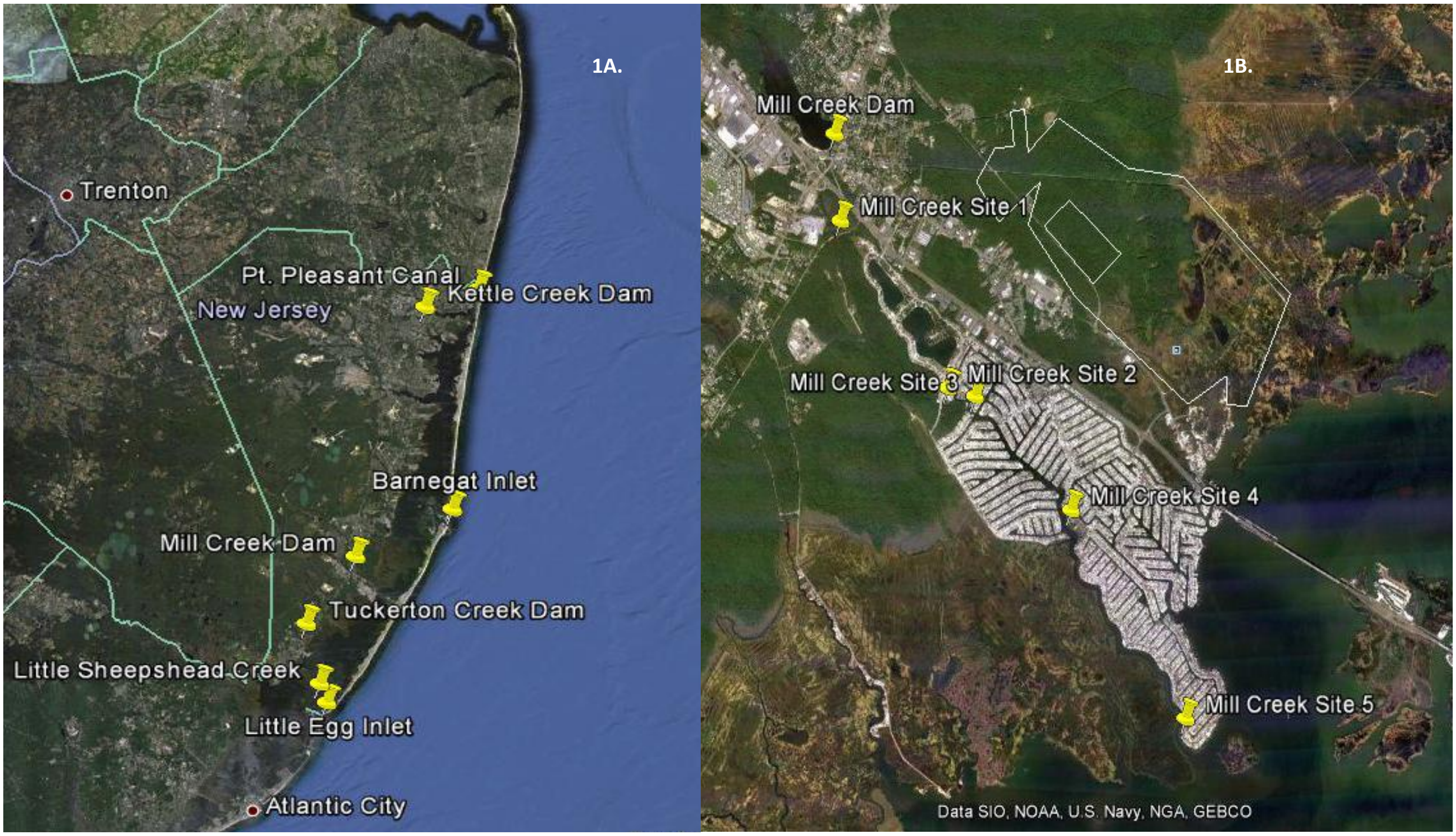

Figure 1A & B. Locations of dams and other collecting sites in Barnegat Bay. Exchange of *Anguilla rostrata* glass eels from the ocean occurs through Little Egg Inlet, Barnegat Inlet, and possibly Point Pleasant Canal (A). Locations of collection sites along Mill Creek from the face of the dam to the mouth of the creek (B).

Figure 2A &B. Polyethylene rope strands unraveled into tufts (A) that are inserted in plastic bowl and clay bottom (B) to make a full eel collector.

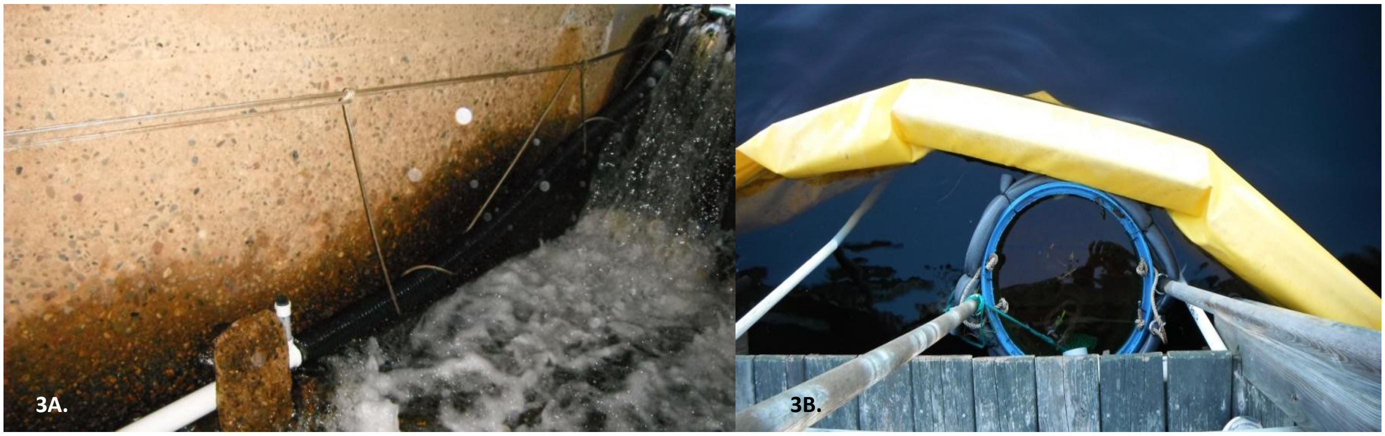

Figure 3A &B. View of corrugated pipe extended below Route 9 at the Tuckerton Creek dam. Suspended with rope to allow better flow and angle of ascent (A) and water surface view of the live box constructed out of “deep tub, secured with floats and PVC piping for stabilization (B).

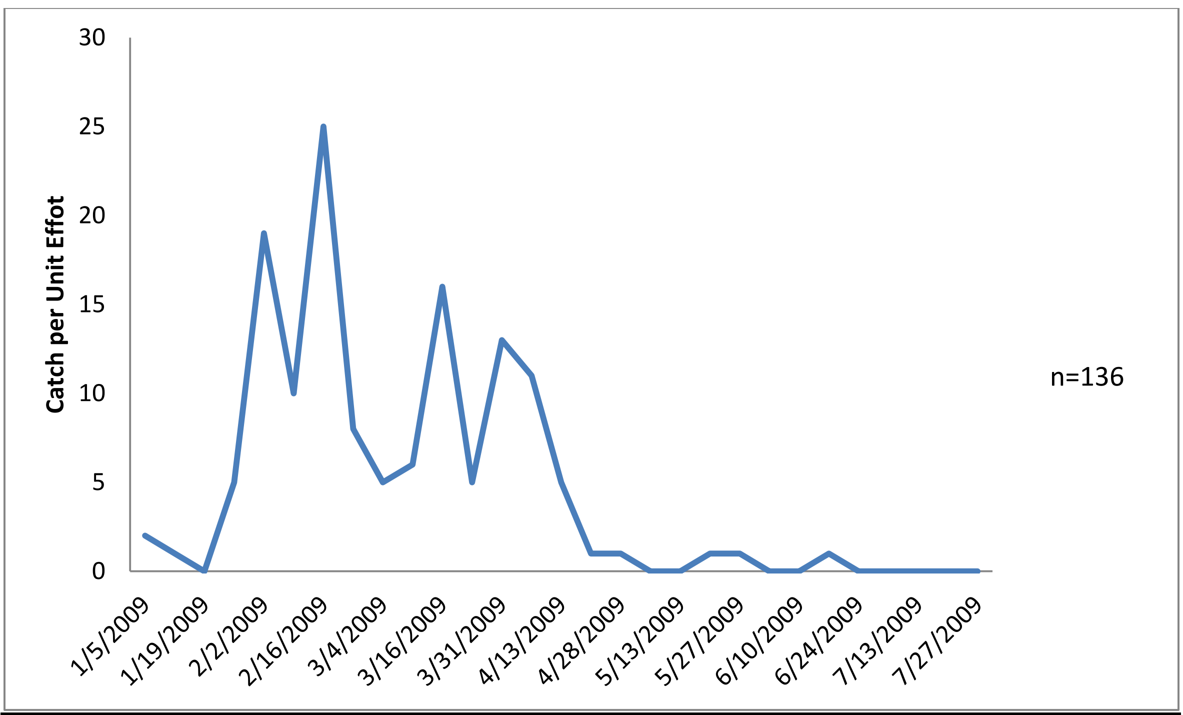

Figure 4. Typical temporal pattern of abundance (CPUE) of glass eels (n= 136, in 29 night time samples) at Little Egg Inlet based on 2009 collections. Catch per Unit Effort was averaged based on three tows in one night per week.

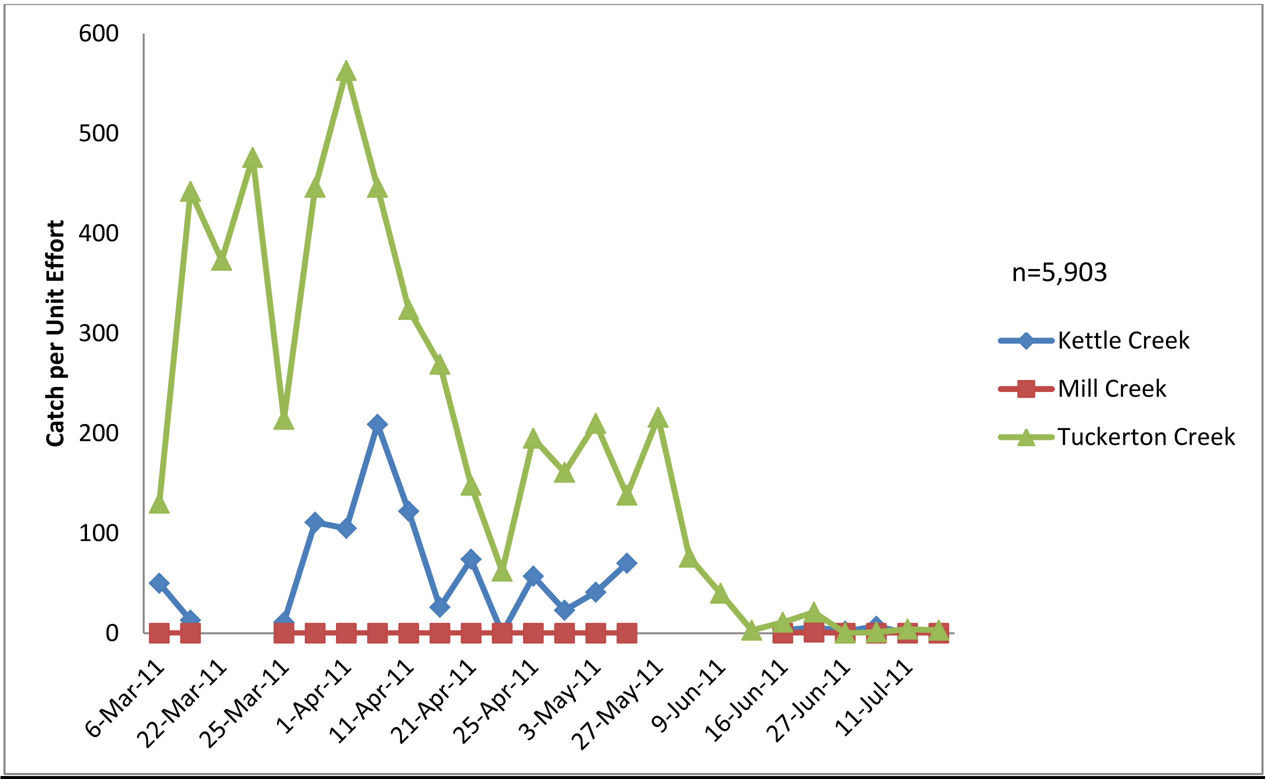

Figure 5A. Occurrence and abundance of glass eels at dam sites, 2011. See Figure 1 for locations.

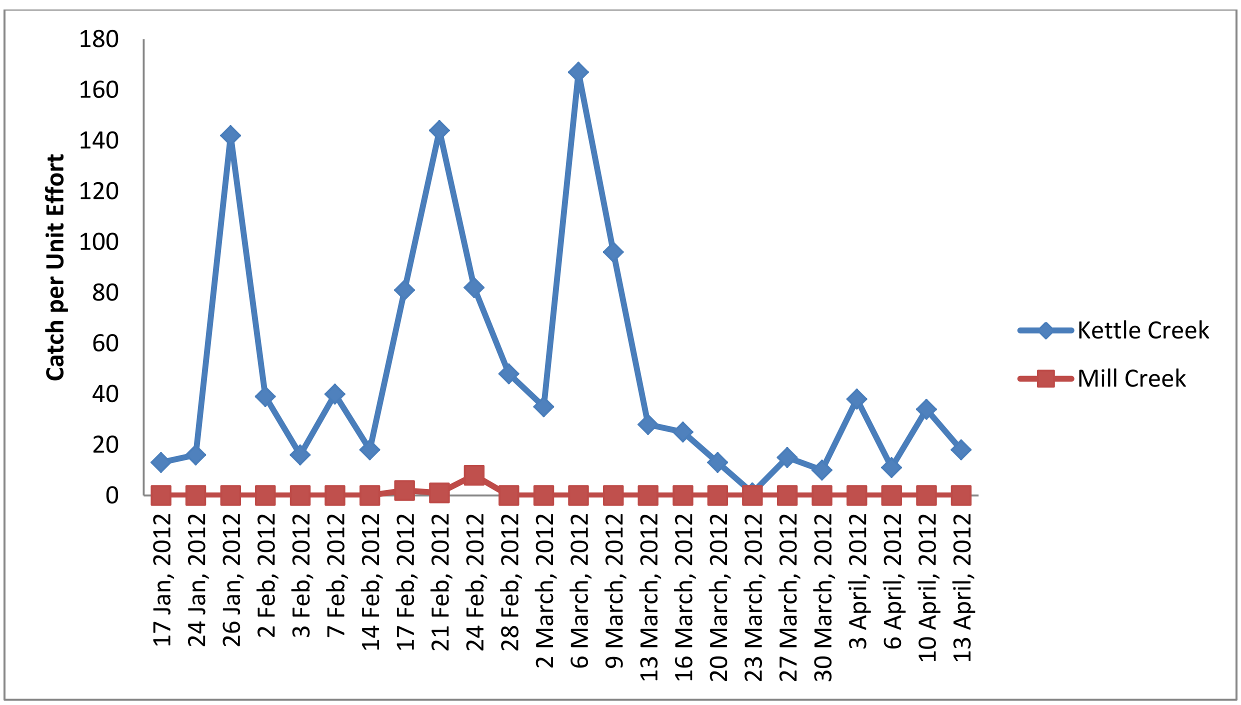

Figure 5B. Occurrence and abundance of glass eels at dam sites, 2012. See Figure 1 for locations.

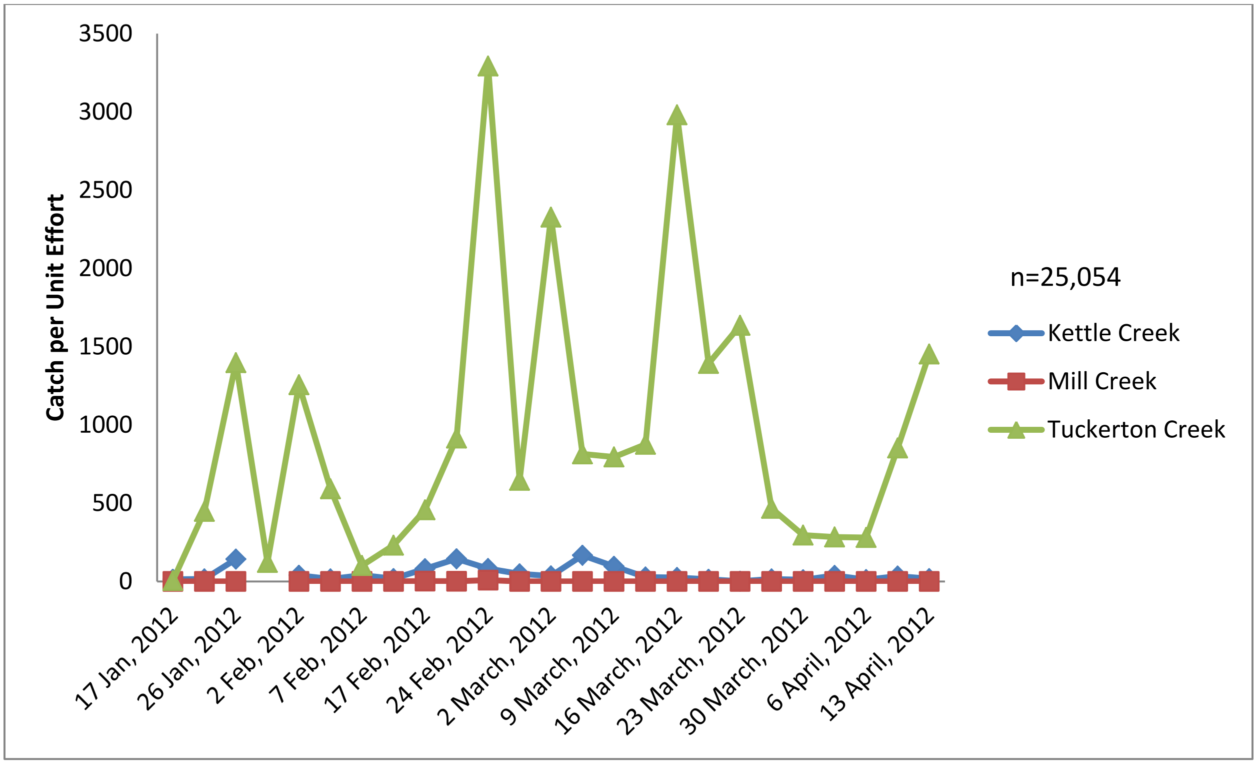

Figure 5C. Occurrence and abundance of glass eels at dam sites, 2012. See Figure 1 for locations.

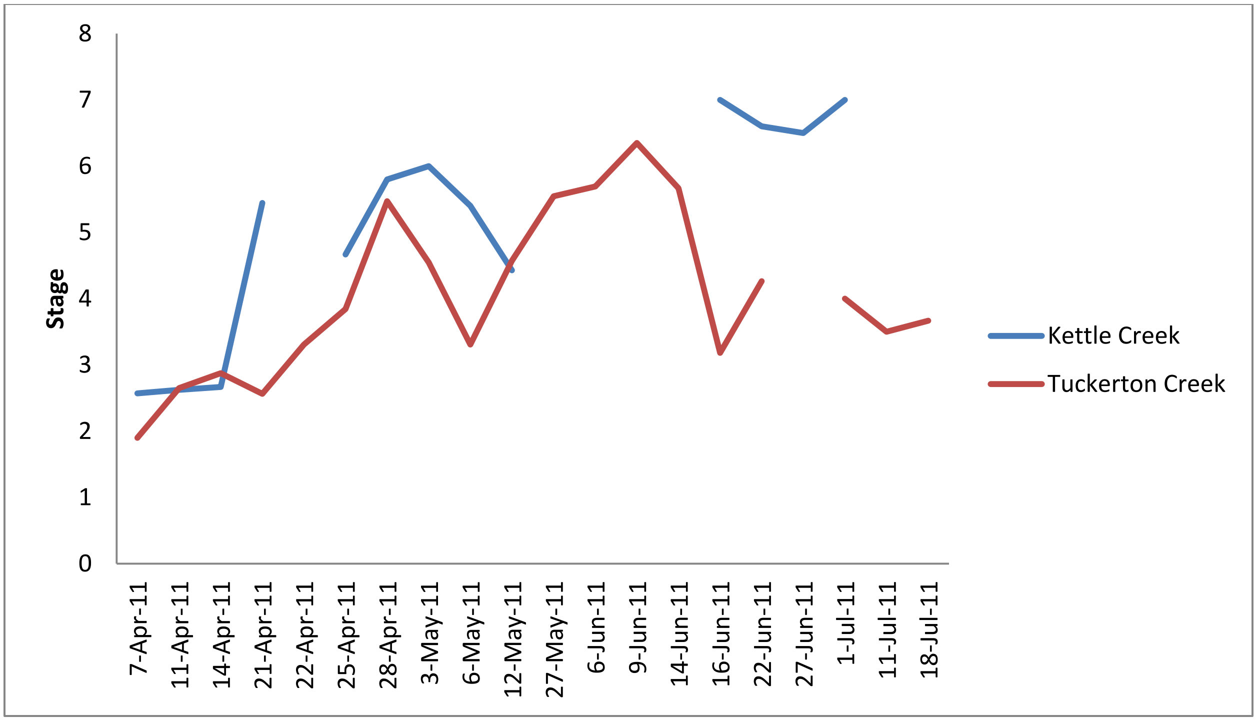

Figure 6A. Occurrence of glass eels by mean development stage at Tuckerton and Kettle creeks, 2011. Mill Creek not plotted because glass eels were rare.

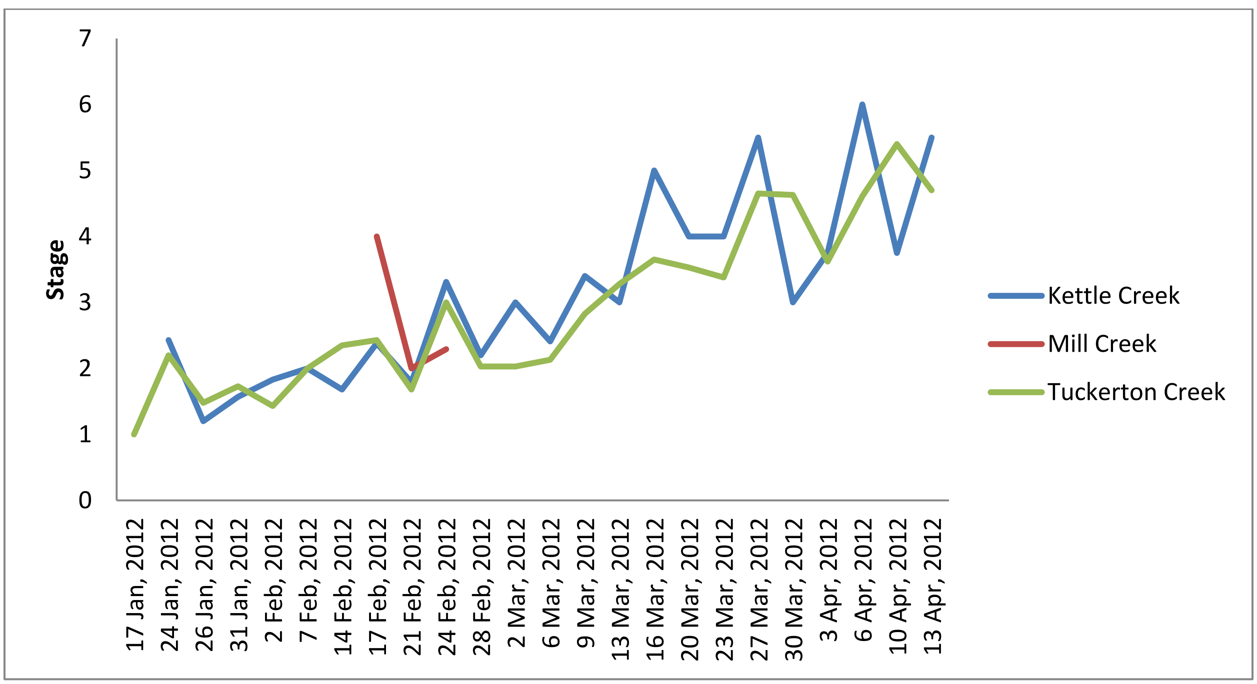

Figure 6B. Occurrence of glass eels by mean development stage at Tuckerton, Kettle, and Mill creeks, 2012.

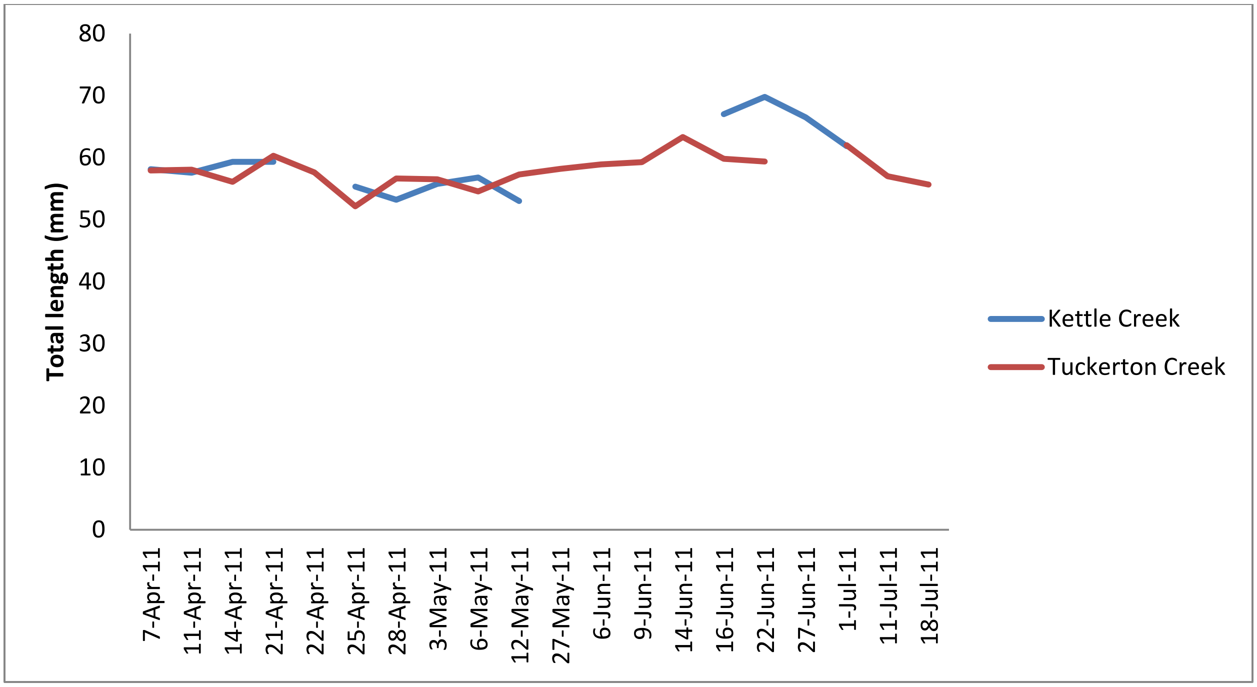

Figure 7A. Occurrence of glass eels by mean length at Tuckerton and Kettle creeks, 2011. Mill Creek not plotted because glass eels were rare.

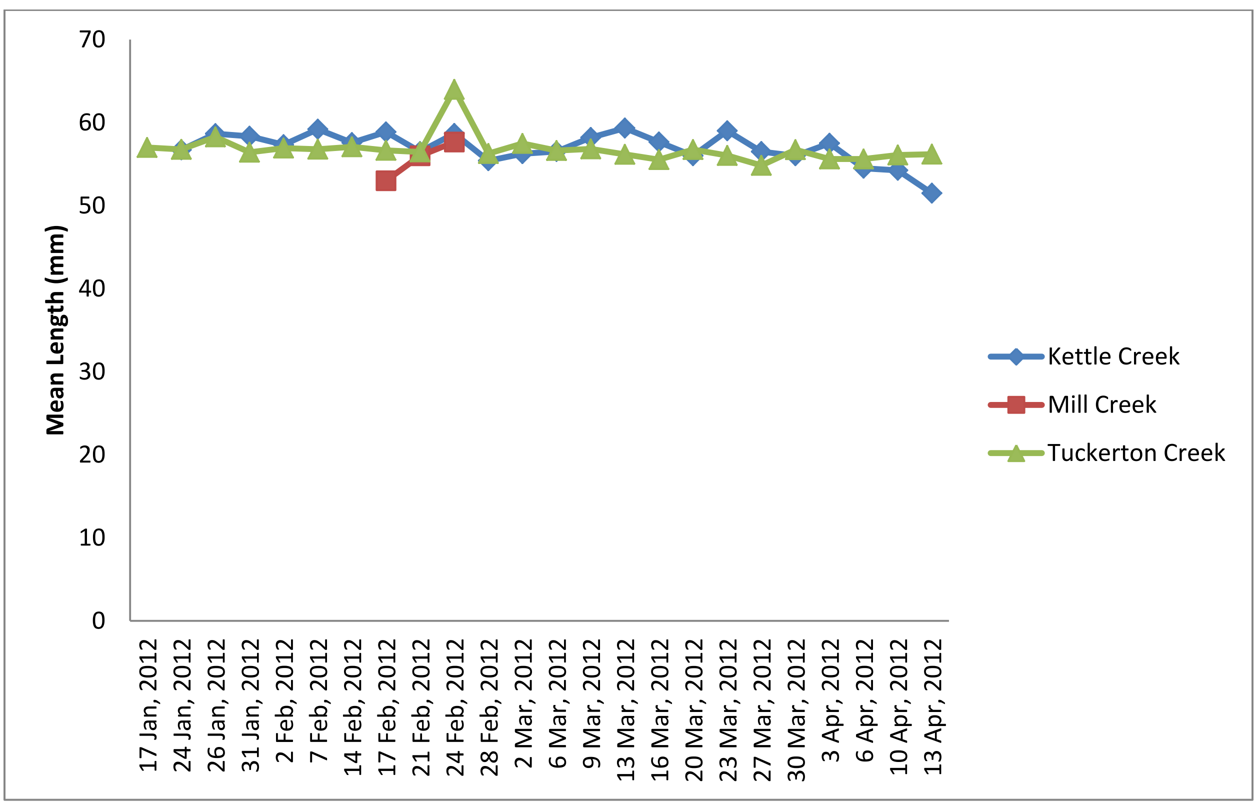

Figure 7B. Occurrence of glass eels by mean length at Tuckerton, Kettle, and Mill creeks, 2012.

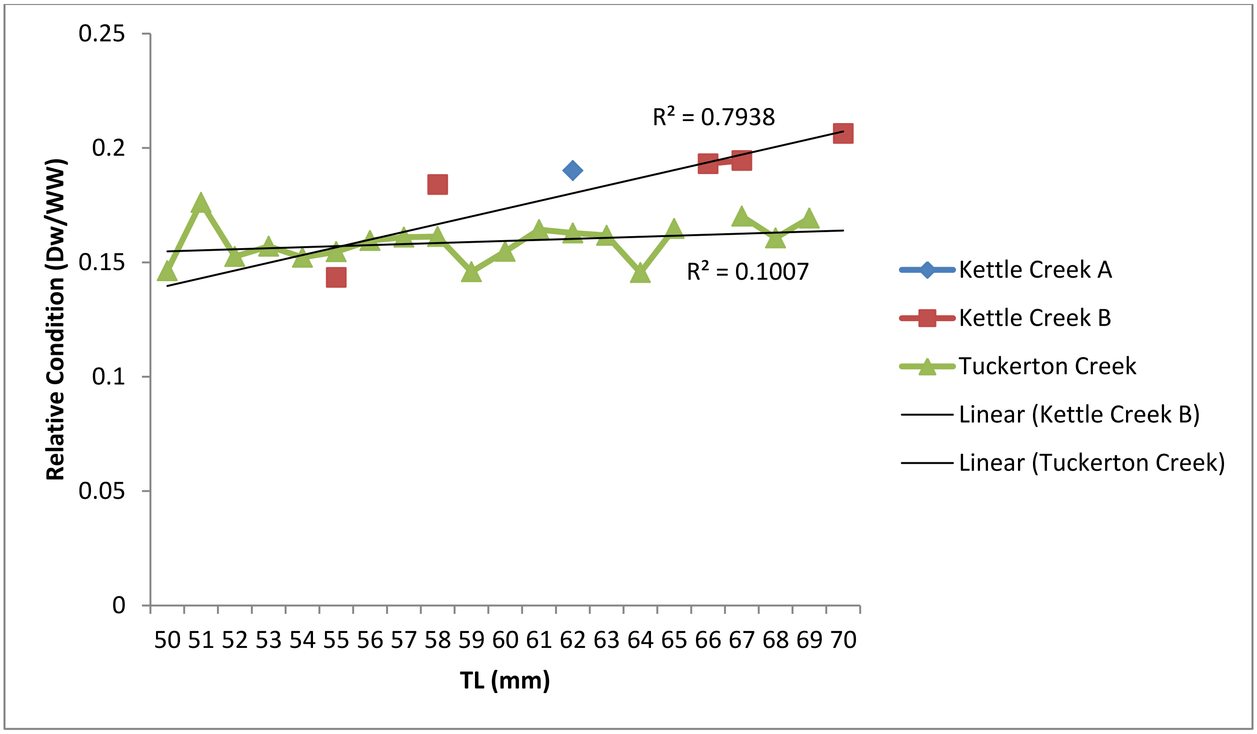

Figure 8. Relative condition of glass eels with increasing total length in 2011. Relative condition is a ratio determined from glass eel dry weight and wet weight. No glass eels were obtained from Manahawkin to measure for condition. Notation for Kettle Creek "A" and "B" represent two different collection dates at the same site.

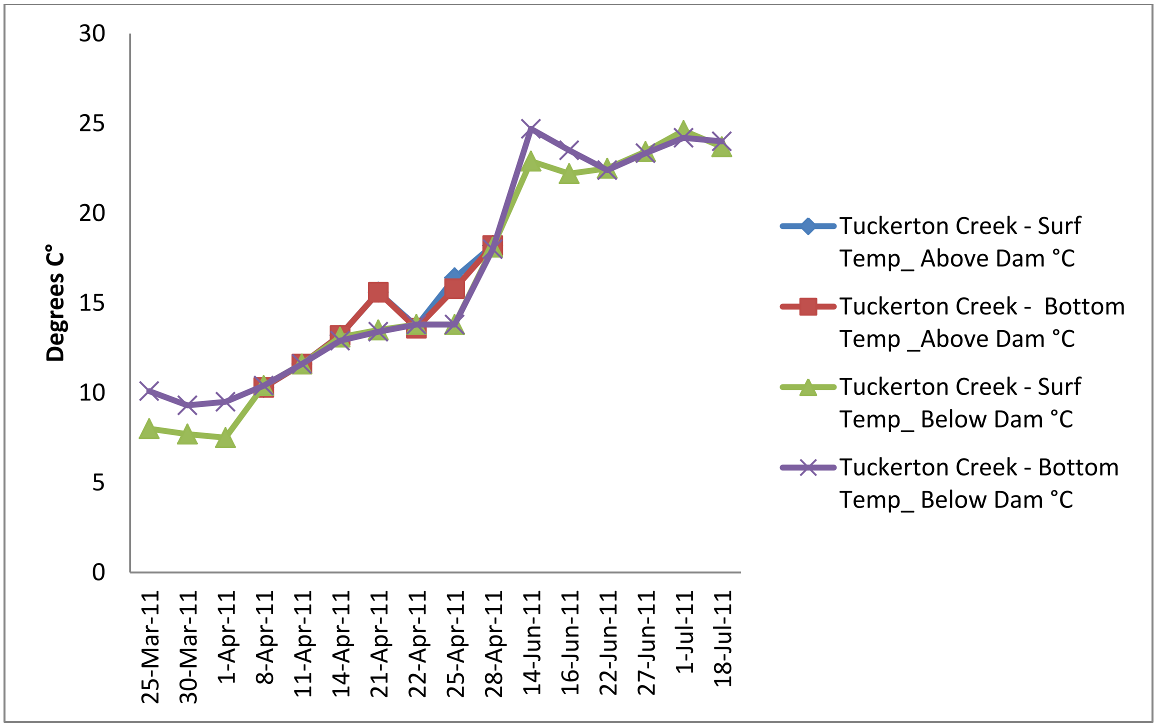

Figure 9A. Tuckerton Creek Temperature Conditions, 2011.

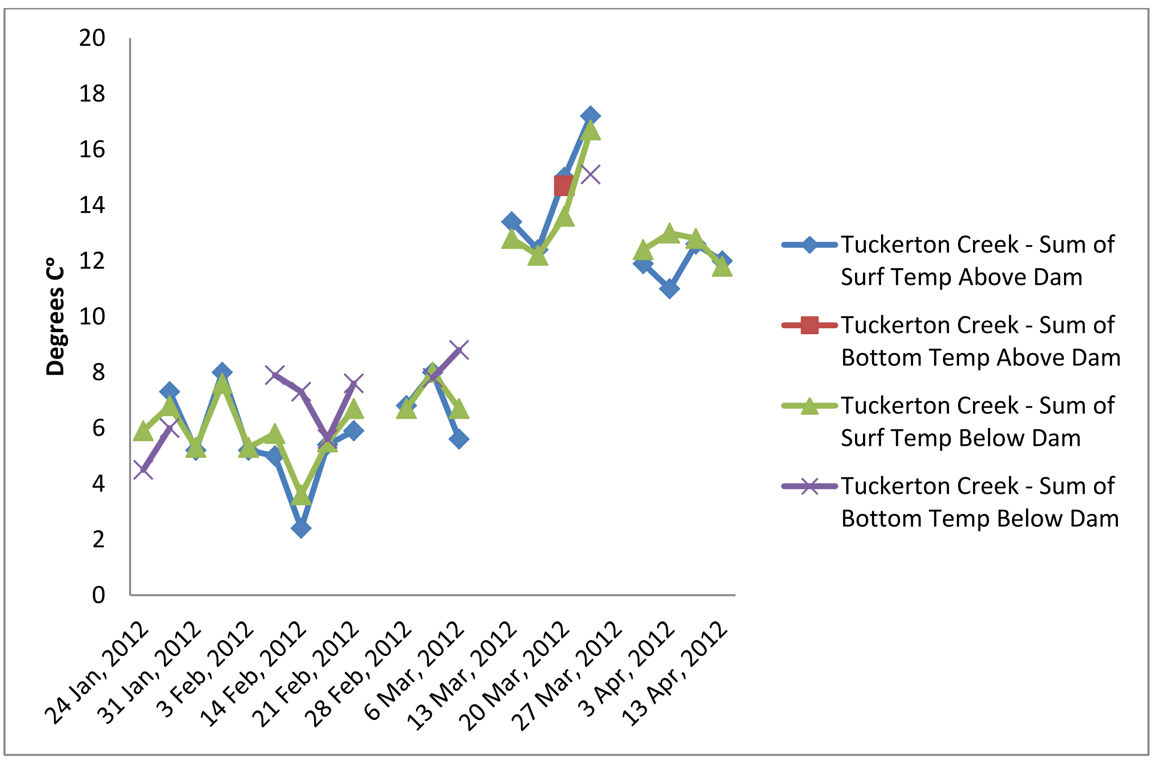

Figure 9B. Tuckerton Creek Temperature Conditions, 2012.

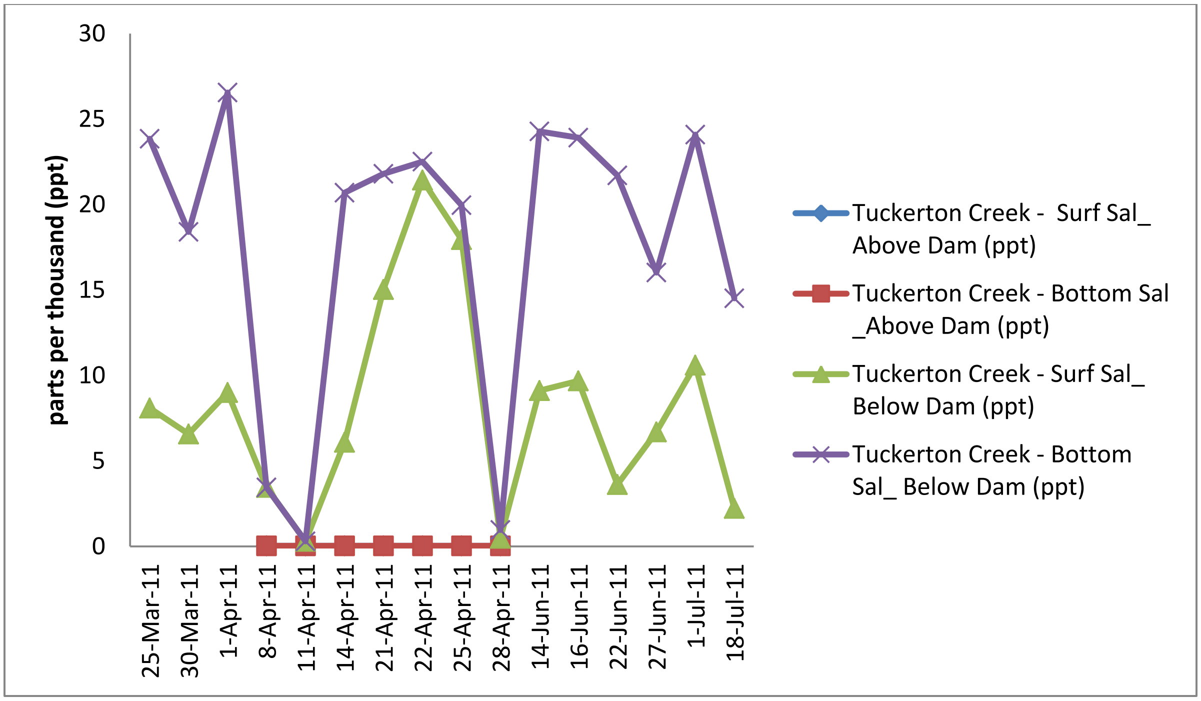

Figure 9C. Tuckerton Creek Salinity Conditions, 2011.

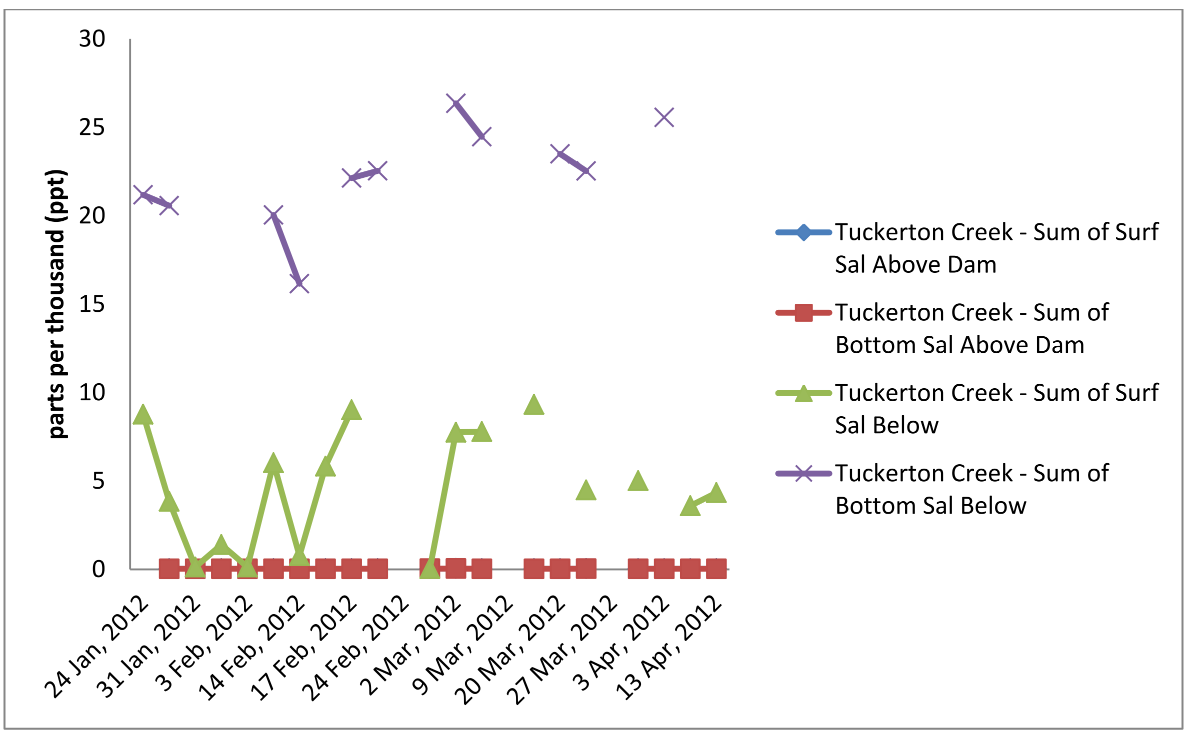

Figure 9D. Tuckerton Creek Salinity Conditions, 2012.

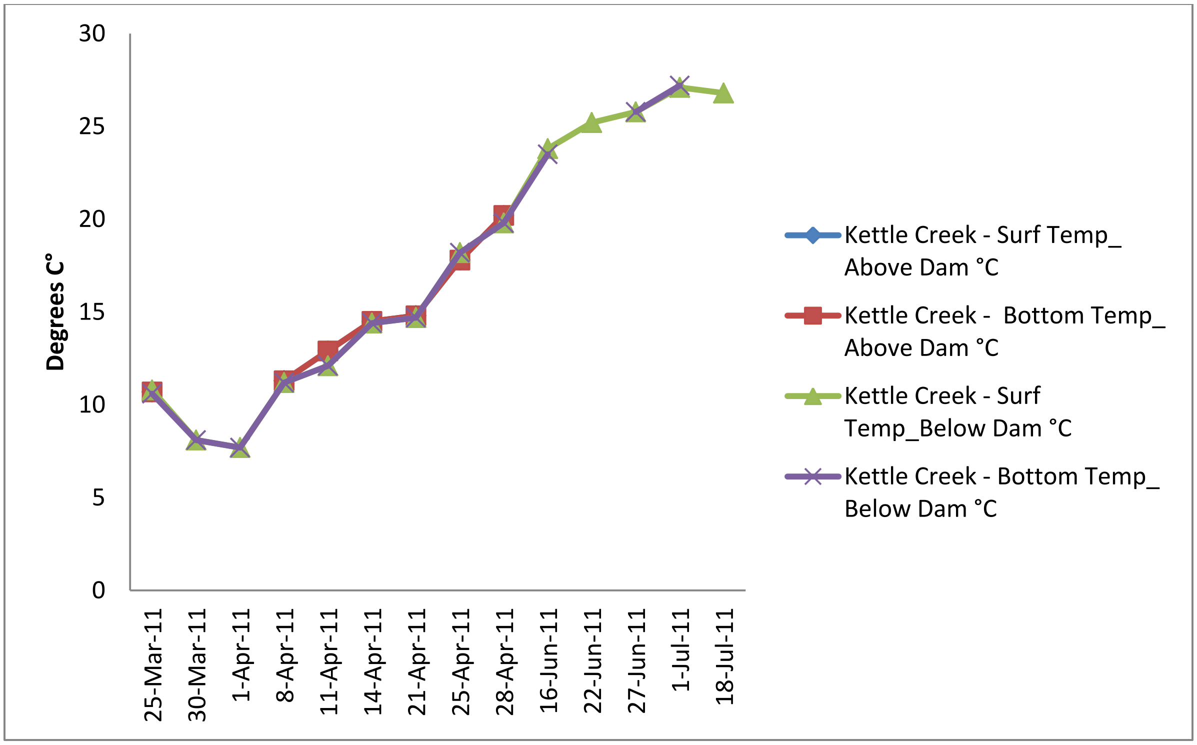

Figure 10A. Kettle Creek Temperature Conditions, 2011.

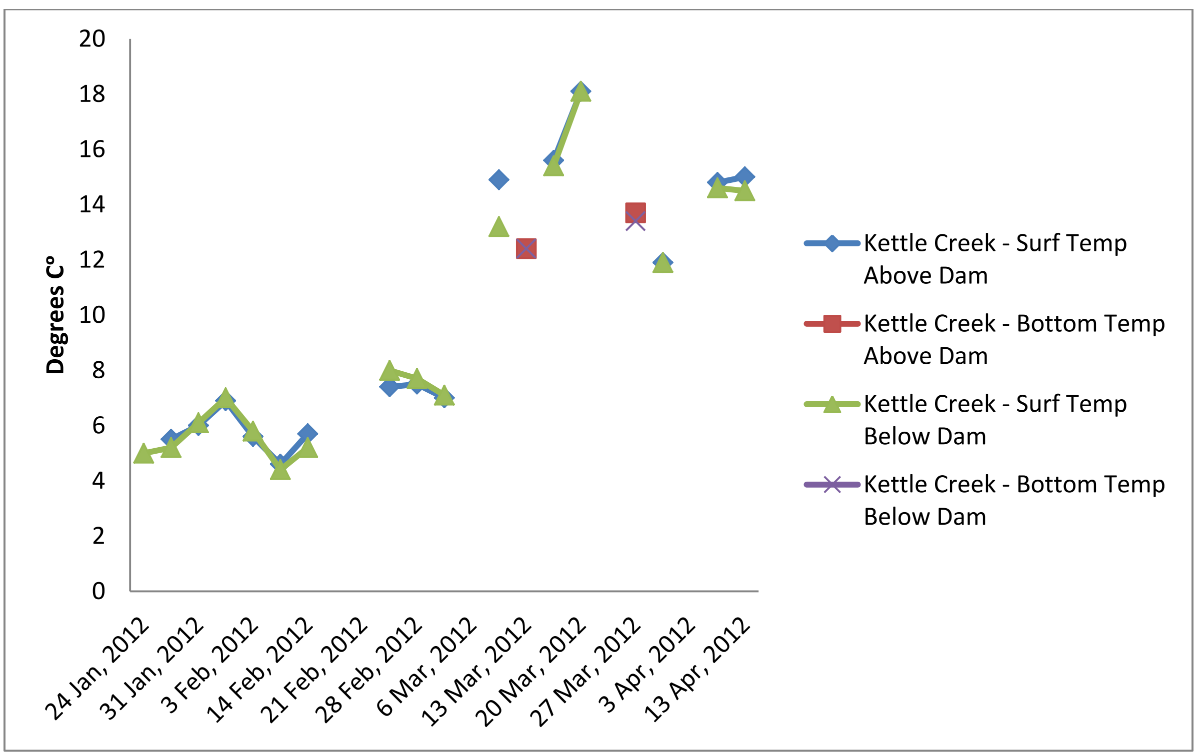

Figure 10B. Kettle Creek Temperature Conditions, 2012.

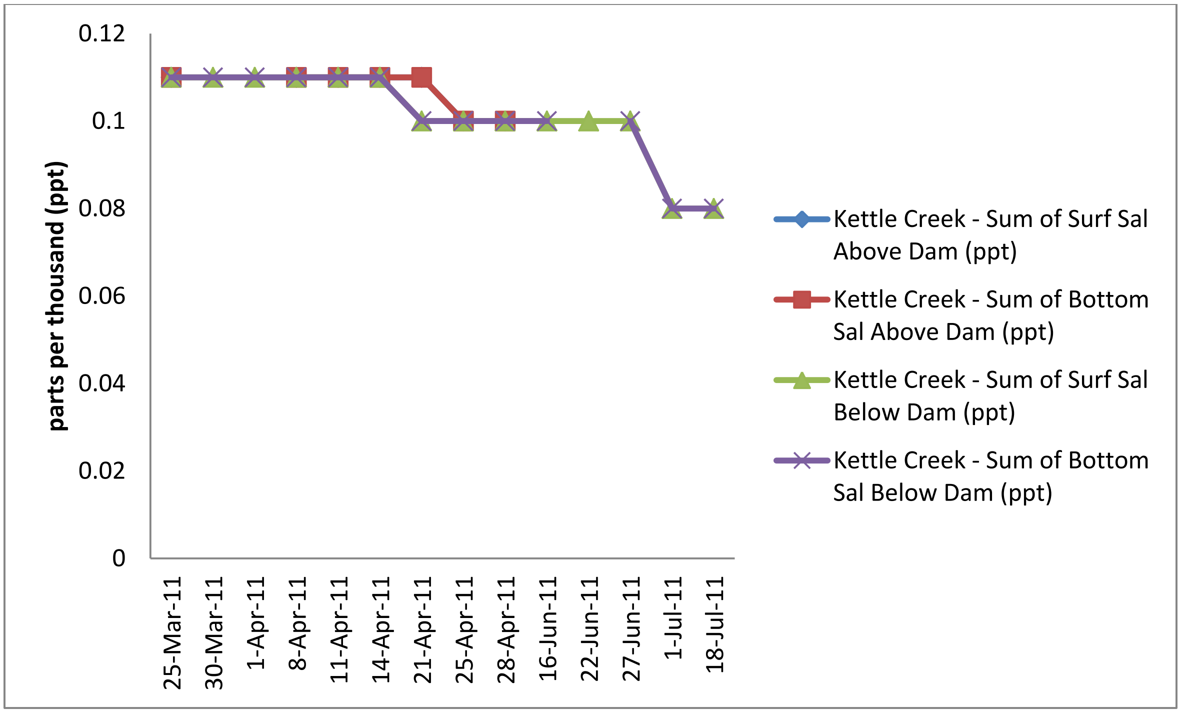

Figure 10C. Kettle Creek Salinity Conditions, 2011.

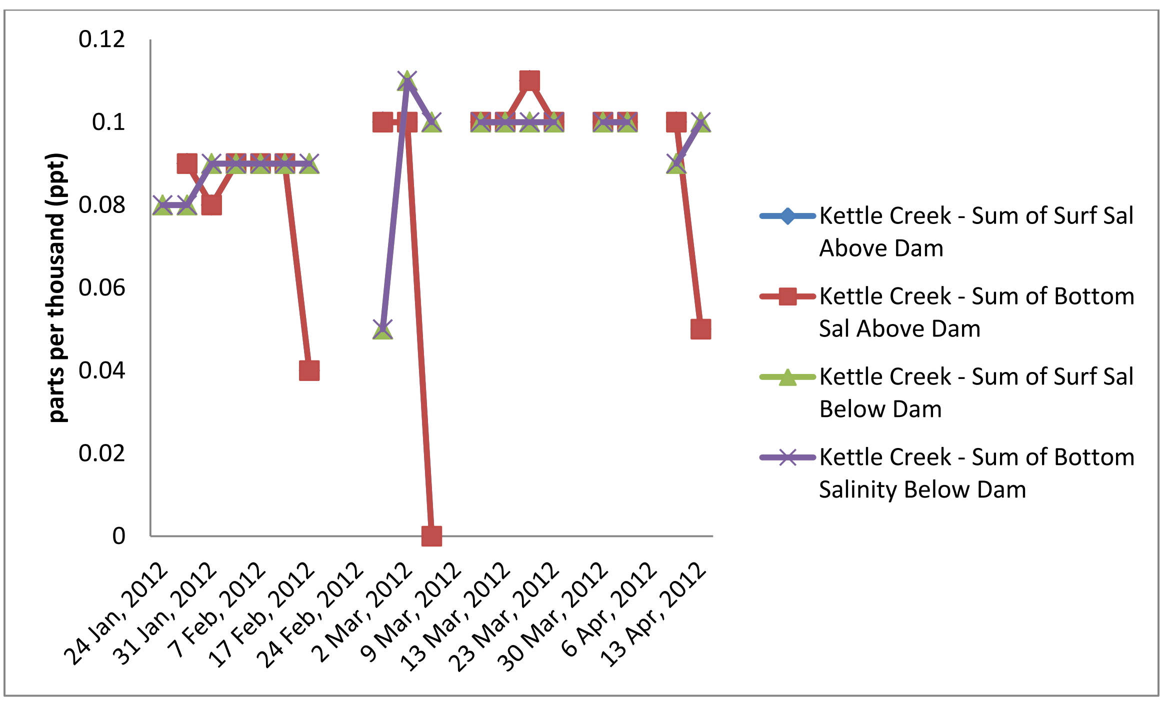

Figure 10D. Kettle Creek Salinity Conditions, 2012.

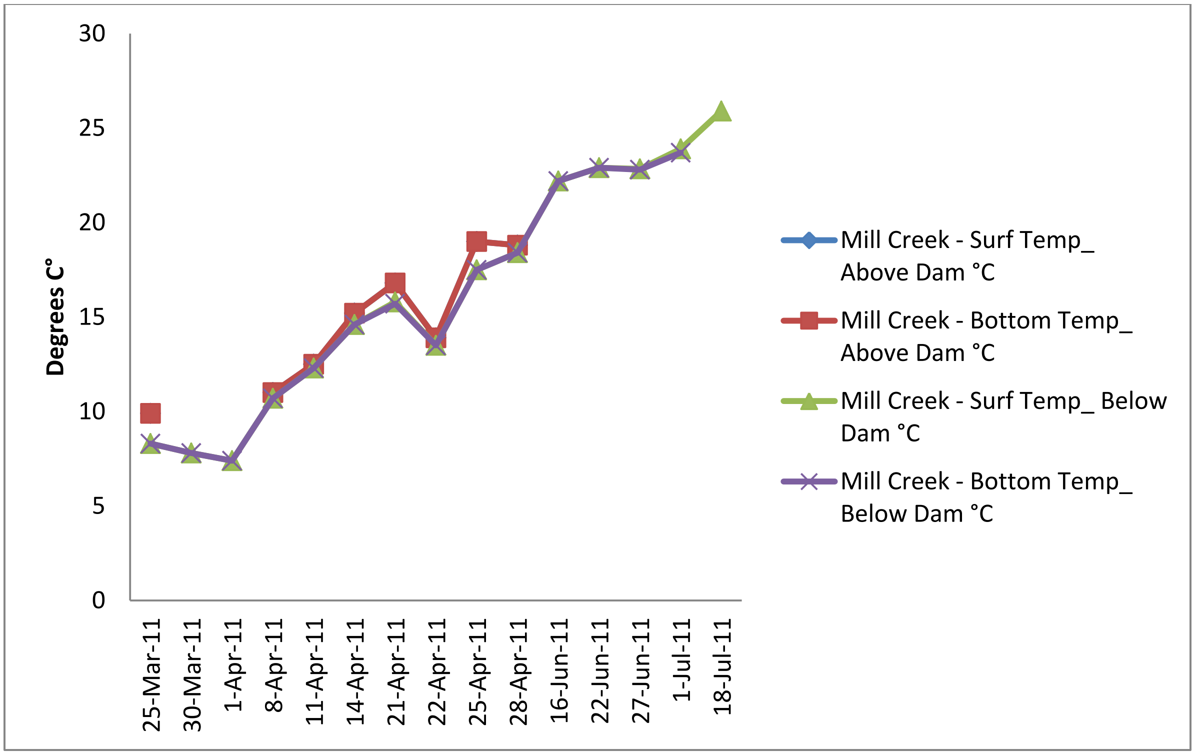

Figure 11A. Mill Creek Temperature Conditions, 2011.

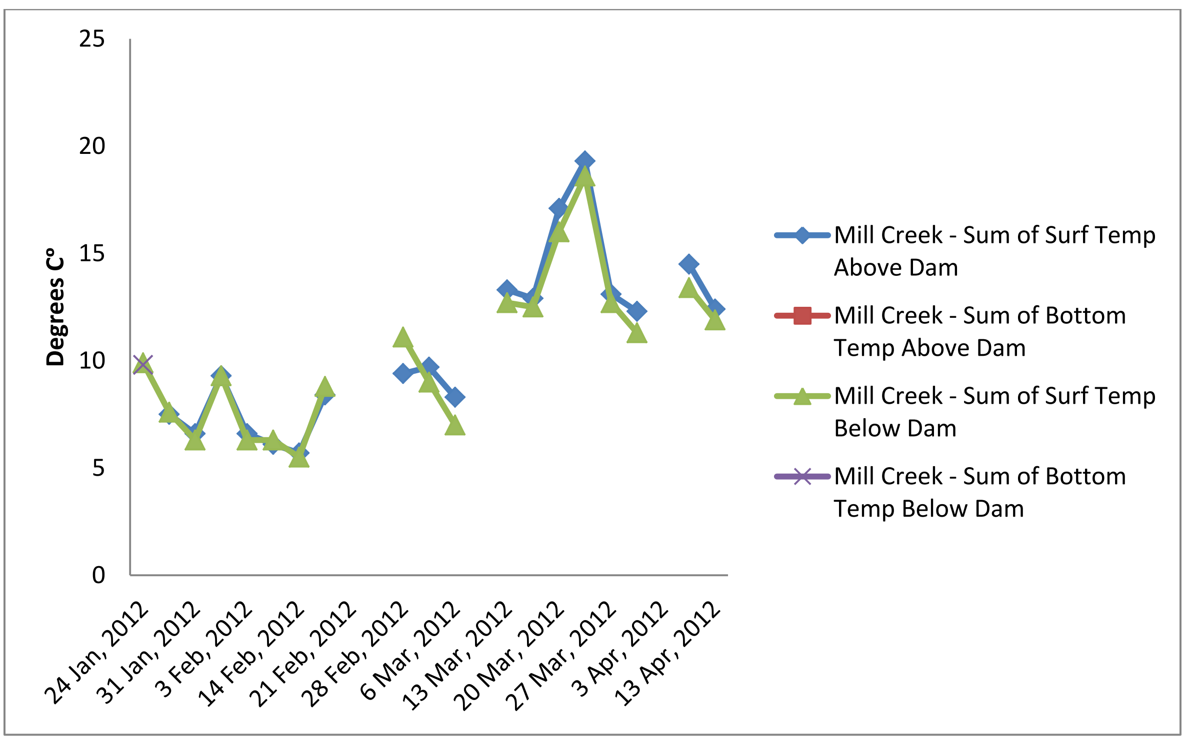

Figure 11B. Mill Creek Temperature Conditions, 2012.

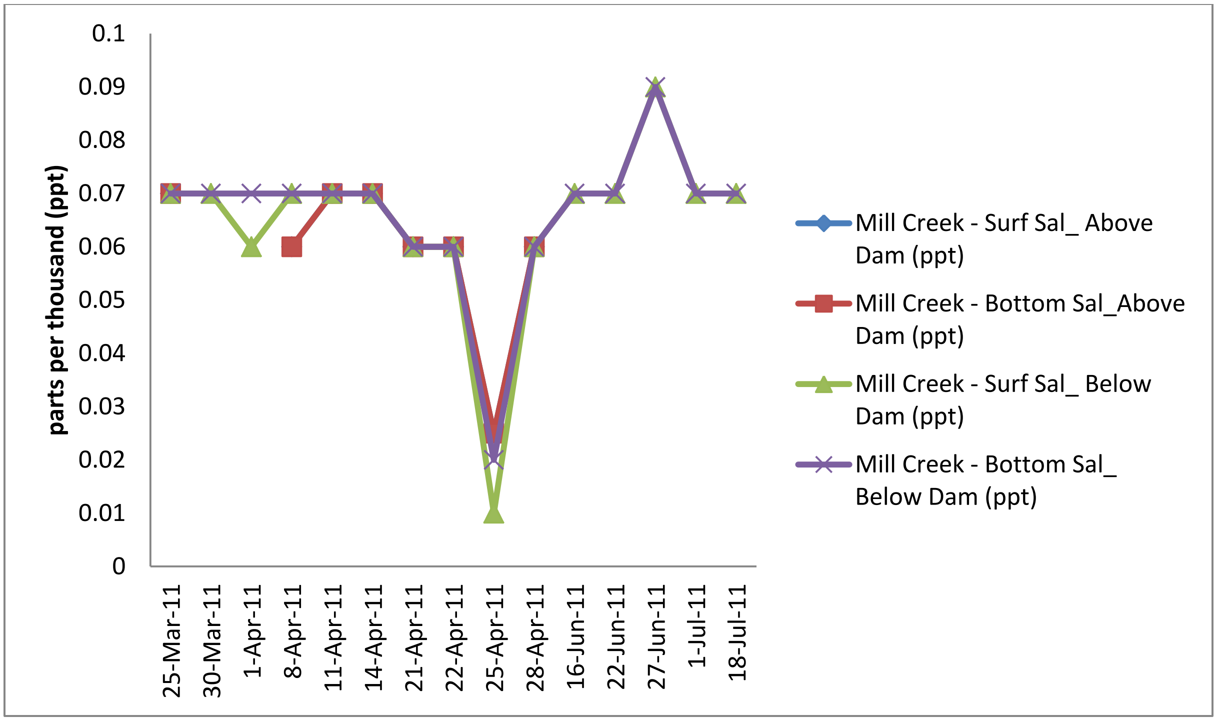

Figure 11C. Mill Creek Salinity Data, 2011.

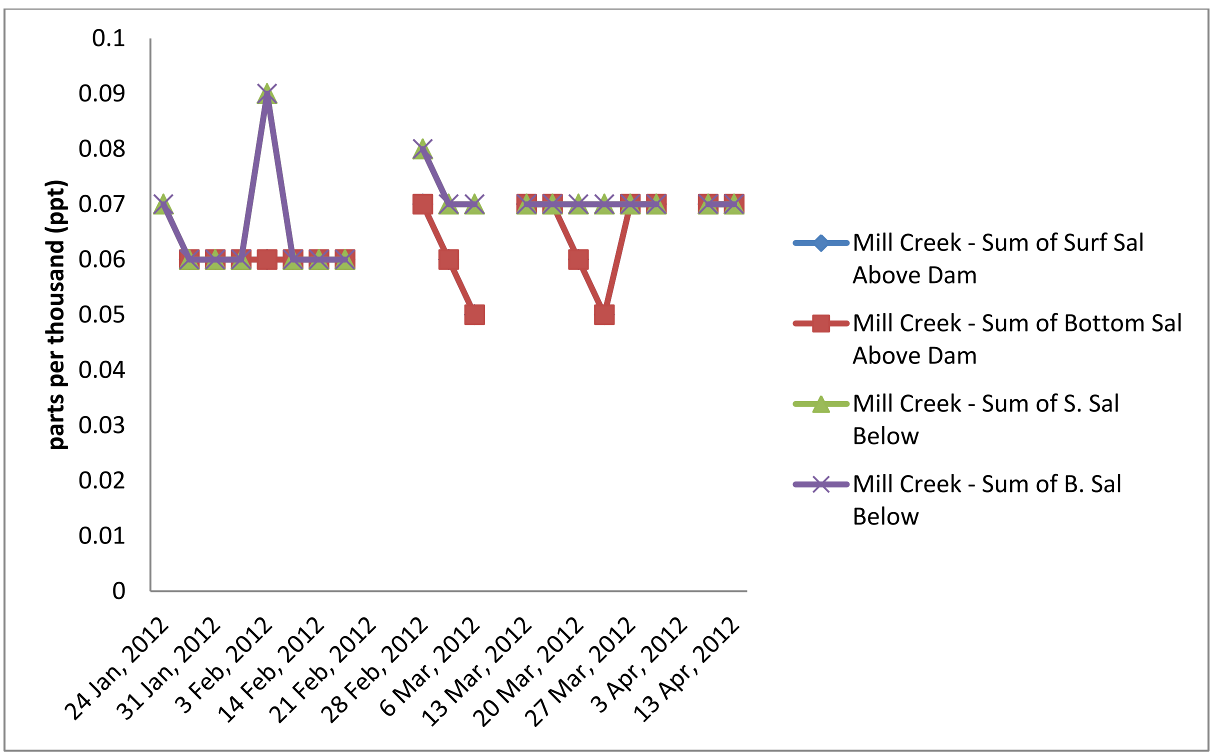

Figure 11D. Mill Creek Salinity Data, 2012.

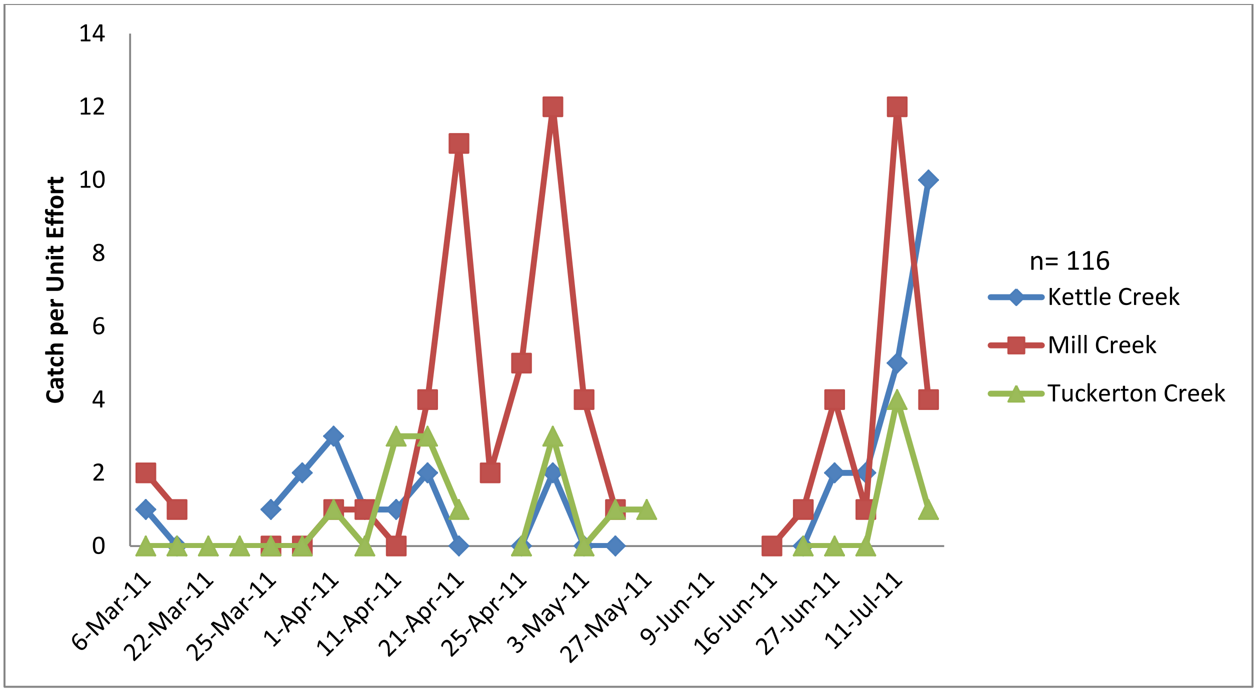

Figure 12A. Occurrence and abundance of elvers at dam sites, 2011. See Figure 1 for locations.

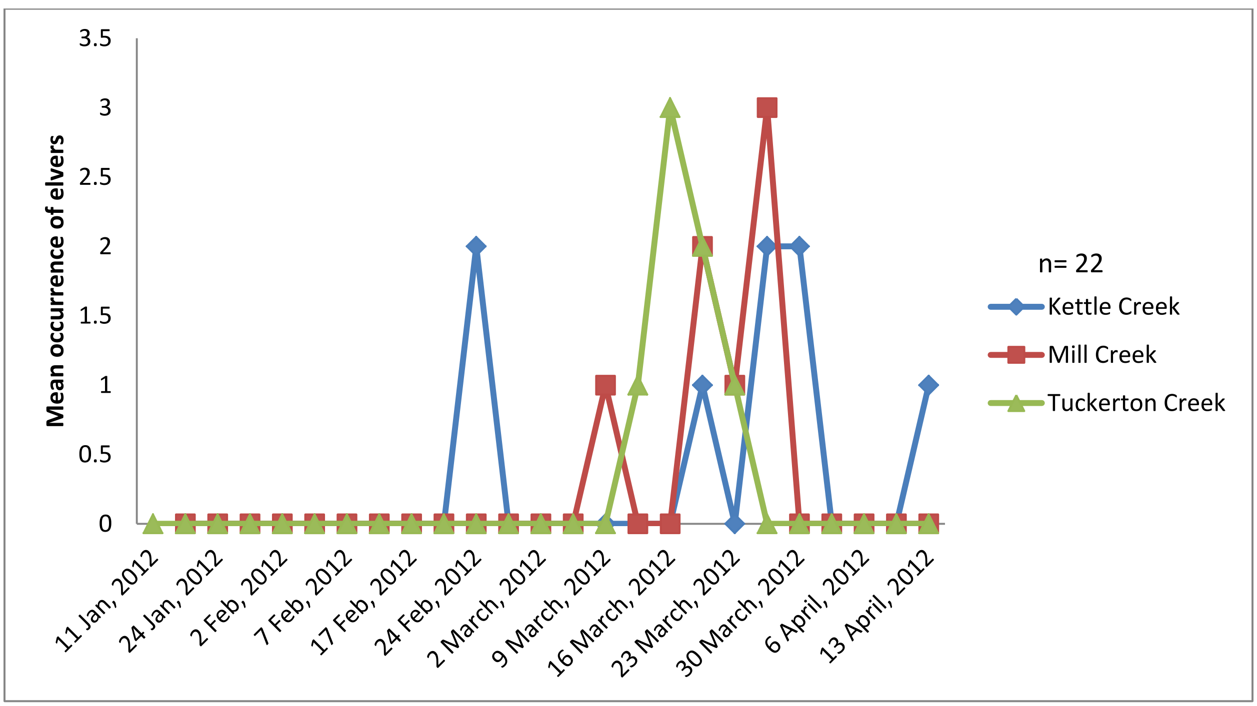

Figure 12B. Occurrence and abundance of elvers at dam sites, 2012. See Figure 1 for locations.