Food Web Structure in a Naturally Fragmenting Stream

Lagunitas Creek, Marin CA

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1.0 Abstract

This study aims to better understand the importance and function of fragmenting streams in riparian zones by describing the changes in aquatic food webs. Stable isotopes were used to measure changes in the food web over the dry season. The site for this study is a riparian zone, John West Fork in Pt. Reyes National Seashore. At JWF 18 pools were sampled three times over a summer for tissue of each representative organism in the food web. Basic habitat data over the summer was collected and compared to isotopic signatures over the summer of key species in each trophic level. The results of this study are still not known, although a niche collapse of the steelhead trout is predicted to occur during the low flow time period.

2.0 Introduction

The watershed of Lagunitas Creek is located in Marin county within the Point Reyes National Seashore. The Point Reyes National Seashore is composed of a number of habitats types that are often divided by vegetation community (Figure 1.1). One branch of the creek is called John West Fork (JWF) which sits in a small valley through a grassland/riparian community that includes bay Laurel, *Laurus nobili*s, blackberry, *Rubus ursinus*, stinging nettle, *Urtica dioica*, and poison oak, *Toxicodendron diversilobum* (Jepson). From the viewpoint of the whole watershed vegetation adjacent to the stream plays a critical role in the aquatic food web directly because the vegetation is a primary energy source for the stream (Voshell, 2002). Within the stream an array of macroinvertebrates break the riparian plant matter down according to the functional roles they play within the system. For example, cadissflies are shredders and collectors, ingesting mainly leaves, while snails are scrapers who consume the periphyton which grows on rock surfaces in the stream. (Merrit et al, 2007). The ecological connections among functional feeding groups can be described as a food web. In this way the food web structure maps the energy flow between organisms and can serve as an indicator of ecological integrity. The primary objective of this study was to examine the changes in the food web structure within various pools along JWF as surface flow decreases during the dry season.

Within a Mediterranean climate regime stream systems have both wet and dry periods due to seasonal rainfall patterns (Cain et. al, 2011). During the wet season, the JWF has continual flow that slowly decreases during the dry season. In local areas along the surface, flow will cease, leaving isolated pools of water that shrink as the dry season continues. The organisms caught in the pools are then limited to the resources within the pool. This drying process produces ecological fragmentation(Cain et. al, 2011 and Voshell, 2002).

JWF is also partially isolated from the downstream region because of a small dam before the confluence with the main creek. Steelhead trout (*Oncorhynchus mykiss*) are the only fish species found upstream of the dam during the dry season because the other fish species downstream cannot jump over the dam. The specific run of steelhead trout within the JWF is a federally listed Threatened & Endangered species. In order to protect the steelhead trout it is essential to understand the ecosystem functions it relies on. The steelhead trout is the only top predator above the dam and plays a significant role in the maintenance of the stream studied at JWF.

Dry season riparian fragmentation, as a process is not fully understood. In aquatic systems the fragmentation process can be part of a natural cycle, where each isolated pool forms a "habitat island" until increased water flow connects the isolated pools in the fall (Cain, 2011). Understanding the changing ecology of naturally fragmenting systems and providing steelhead management suggestions are the major objectives of this study.

3.0 Methods

Using stable isotopes of carbon and nitrogen we examined the aquatic food web structure of isolated pools within the JWF that dry at various times over the summer. To do this we collected tissue samples from all trophic levels (algae, insects and fish) at three time periods for each pool: high flow, low flow and no flow.

3.1 Habitat Measurements

Changes in aquatic habitat were quantified weekly. There were sixteen pools in the JWF, with enough water to be included at the time of the first tissue collection. For each pool, three lengths, and widths were recorded as well as thalweg (i.e. deepest) depth of each pool. The riffles above each pool were also measured until the riffle ceased surface flow.

3.2 Stable Isotopes

Trophic or food web structure consists of determining feeding relationships among organisms. We employed stable-isotopes as a tool for examining trophic structure of the individual pools. This method is based on the principal that carbon and nitrogen isotope ratios are specific to an organism based on what the organism eats (Layhee, 2011). Therefore, energy flow in a food web is recorded in the changes in carbon and nitrogen stable isotope ratios.

Carbon is a useful element because C^{12} is selected for by some photosynthesizing species. C^{13}, a stable isotope of carbon is found in higher concentrations in the organisms that do not select for C^{12}(Layhee, 2011). For example periphyton does not select for C^{12} and will therefore have a more negative carbon signature than Phytoplankton which actively selects for C^{12}. Organisms which eat periphyton and phytoplankton, will then have the same carbon signature as the organism the predator consumed because carbon isotopes are conserved as you move up the food chain.

Nitrogen is another useful element for ecological studies because N^{15}, (an isotope of N^{14}), is incorporated into an organism's body as it is metabolized while the lighter N^{14} is excreted. (Layhee, 2011 and Vander Zanden, 2003) The N^{15} ratio therefore increases 3.4Nitrogen units at every trophic level, (see figure 3.1). The nitrogen ratio can therefore be used as an indicator of the trophic level of the organism. For example a predator like a snail will have a nitrogen ratio 3.4 units above the snail's food source. All tissue samples are sent off for isotopic analysis in a mass spectrometer at UC Davis.

3.3 Tissue Collection: Leaf litter and filamentous algae

Leaves fall into the stream from the riparian vegetation, while filamentous algae grows on the rocks within the pools that have enough sunlight for photosynthesis to occur. Leaf litter and filamentous algae were collected by hand from each pool at each time period and were placed in a plastic bag and frozen until they are dried and pulverized for isotope analysis.

3.4 Tissue Collection: Periphyton

Periphyton (attached algae) grows on the rocks within the stream bed (Voshell, 2002) The periphyton forms a thin 'slimy' layer on the top of the rocks. This thin film is collected by brushing with a toothbrush into a tray. The tray is slightly diluted with deionized water and scanned visually for insects and debris that are removed with tweezers. The sample is then frozen until it can be dried for isotope analysis. Enough periphyton is collected for a dry .1g pellet.

3.5 Tissue Collection: Aquatic Invertebrates

Two methods are used to collect aquatic invertebrates, D-net and Surber sampling. The D-net is hand-held mesh net used to qualitatively collect representatives of all invertebrate living in the stream. Ten second sweeps are spent within each square meter of the pool (Bogan et. al, 2011) pulling the net along the bottom of the pool and sweeping back through the area to pick up the invertebrates in the water column. Additional snails and water striders were collected when one D-net pass did not collect them.

The Surber sampler was used to quantitatively sample the aquatic macroinvertebrate community and provide an estimate of the number of insects in one square foot of stream bottom. For ninety seconds one hand is used to turnover the floor of the pool. Water flow pushes the invertebrates from the water column into the net downstream, Figure 3.2. The surber is done twice at random locations within each pool. All macroinvertebrate collections are stored in ethanol, sorted under a microscope, and the representative organisms are dried and ground into a powder for isotope analysis.

3.6 Tissue Collection: Terrestrial Invertebrates

Invertebrates that fall into the stream are sampled by setting pan traps along the sides of each pool and riffle. Pan traps are shallow trays filled with water and biodegradable soap. Three traps were set at each pool and at the connected riffle. (Voshell, 2002) All terrestrial invertebrate collections are stored in ethanol, sorted under a microscope, and the representative organisms are dried and ground into a powder for isotope analysis.

3.6 Tissue Collection: Fish

Steelhead trout were collected by back pack electrofishing and hand seineing. From each fish greater than 60mm long and two grams in weight, a tissue sample was taken with a dorsal fin clip. At the same time scales were removed and saved from the lateral pectoral fin region of the fishes body. All steelhead were also PIT tagged. For very small fish, only dorsal fin clips were taken. All captured steelhead trout were weighed and measured in length. All fish were returned alive to the same pool after processing.

4.0 Results

The isotope analysis is not complete; the third tissue collection was completed September 10th 2012. The results discussed here are expected but not actual results. Instead I present Figure 4.1 and Figure 4.2 which can be viewed as hypothesized changes in tropic structure that we expect changes over the summer drying season. Note that the values on the graphs are not specific isotopic signature values.

Also note that on Figures 4.1 & 4.2 there is no primary producer level indicated, because It is known that periphyton isotope data is often too variable to obtain an accurate carbon and nitrogen signature. Instead, the signatures of the primary grazers (snails) provide a more accurate second trophic level.

Known life history information about the feeding habits of the invertebrates and the photosynthesizing system of periphyton and phytoplankton indicate that organisms relying more on periphyton will be on the right side of the carbon-nitrogen bi-plot, Figure 3.1 (Cain et al, 2011). Periphyton is consumed by scrapers such as snails that are able to scrape the periphyton off the rocks. Leaves are consumed by shredders that tear apart the leaf (Voshell, 2002).

In the high flow situations (early summer) the pools are connected to riffles, have high oxygen content, and lower temperatures. When the riffles are connected they carry macroinvertebrates into the pool. The riffles downstream of the pool transport invertebrates and sediment out of the pool. Caddisfly (Trichoptera) and mayfly (Ephemeroptera) larvae are believed to exhibit a more negative carbon signature so they appear on the left in figure 4.1. The dominant taxa caddisfly found at JWF and the majority of mayfly larvae consume phytoplankton. Midges (Chironomidae) consume primarily periphyton. The snails consume mainly periphyton and provide a cornerstone for the least negative carbon signature possible in the food web.

During the second and third collection periods the water flow is low and many riffles have dried up, isolating the pools. Pools with less water have decreased habitat volume, lower amounts of dissolved oxygen, increased sediment buildup, and increased temperature (Cain et al, 2011). These stress factors and limited resources in a low flow area are likely to increase competition within the pools. For this reason we predict that a process called niche collapse may occur (Layman, 2007). Stress tolerant invertebrates such as caddisflies, snails, and dobsonflies are likely to persist. Midge populations will also likely decline but not disappear while it is likely that mayflies will drop completely out of the system. Steelhead isotope signatures will shift to the right indicating increased consumption of dobsonflies (Megaloptera) as they deplete the stonefly, and smaller steelhead population. Dobsonflies will also shift towards the periphyton end of the carbon scale as they deplete the mayfly population which is larger than the midges and therefore easier to consume than the hard shelled snail. Caddisfly populations are likely to decrease in the pools in the later summer as they mature and leave the water for the terrestrial phase of their life cycle. Fewer caddisflies will be likely be available for predators causing a shift in predator reliance on midges and snails.

The population of steelhead is also expected to decrease, as small and weak are culled from the ranks. The steelhead population will continue to decrease as resources collapse. In the pools that completely dry over the summer the steelhead and the majority of the invertebrates will die. In the pools that remain wet until the rainy season the steelhead that remain will have a chance of survival as water flow increases again, bringing oxygen and cold water. Once the pools are connected the steelhead and invertebrates can move up or down stream to access resources (Cain et al, 2011).

5.0 Figures

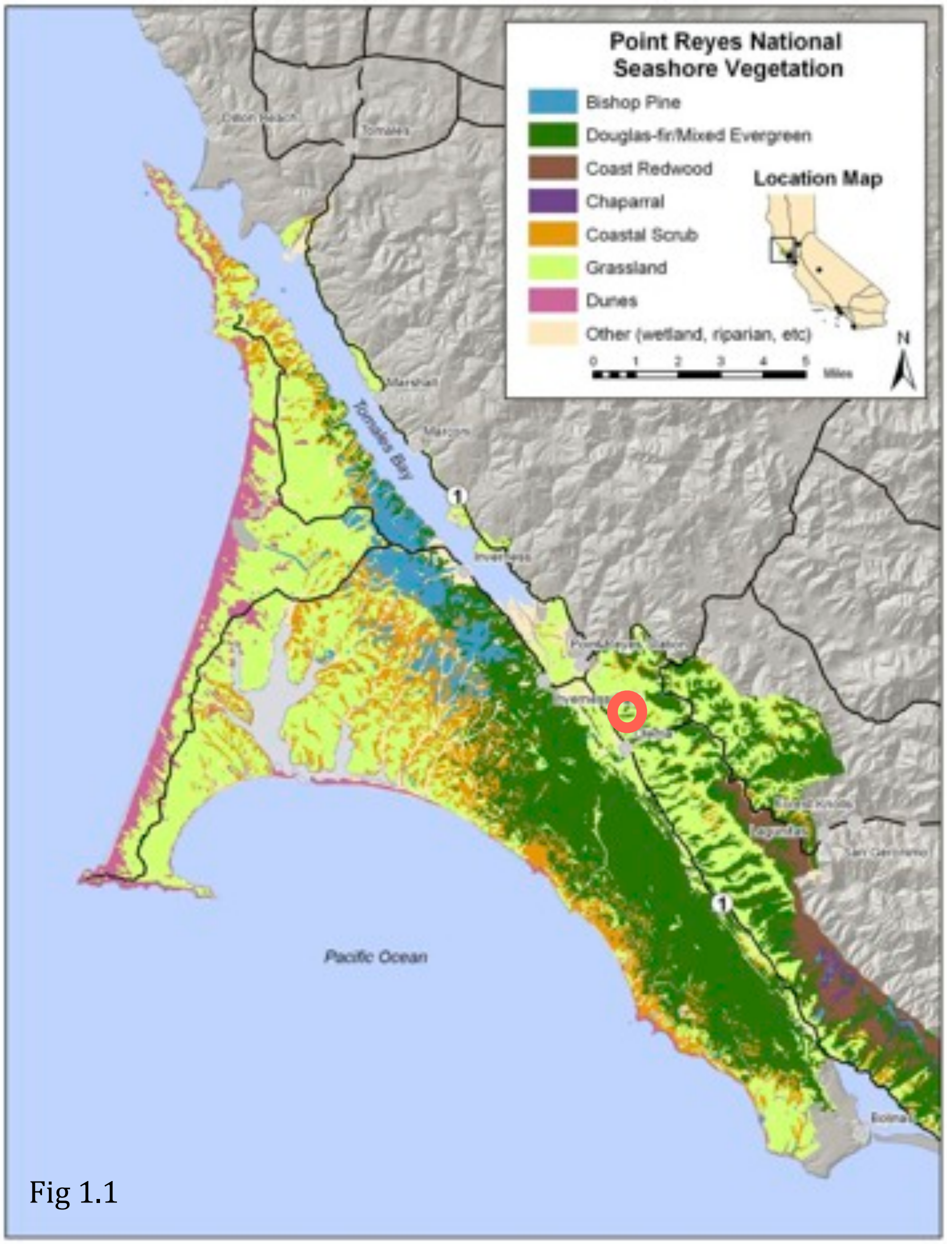

Fig 1.1 Map of vegetation types across Pt. Reyes National Seashore. JWF (in the red circle) is located along Highway1 in the grassland and Douglas-fir mixed evergreen area. The stream at JWF outlets to the Pacific Ocean.

Fig 3.1 Hypothetical Aquatic food web. Isotopic signatures are expressed on a bi-plot with the carbon signature on the x-axis and the nitrogen signature on the y-axis. The carbon signature reflects the energy source. The producers or photosynthesizers select for carbon differently. Species that do not select for C12 will be more negative than the species that do not select for C12. In this example periphyton has a signature of -10. Snails are grazers and eat periphyton and therefore have the same carbon signature (-10). The snails are one trophic position above periphyton and therefore appear 3.4 nitrogen units above periphyton (-10, 6.4). The fish in this example have eaten half snails and half zooplankton and therefor have a carbon signature half way between -30 and -10, -20. The fish eat organisms in the secondary trophic level and so appear 3.4 nitrogen units above them, at 9.8 nitrogen units.

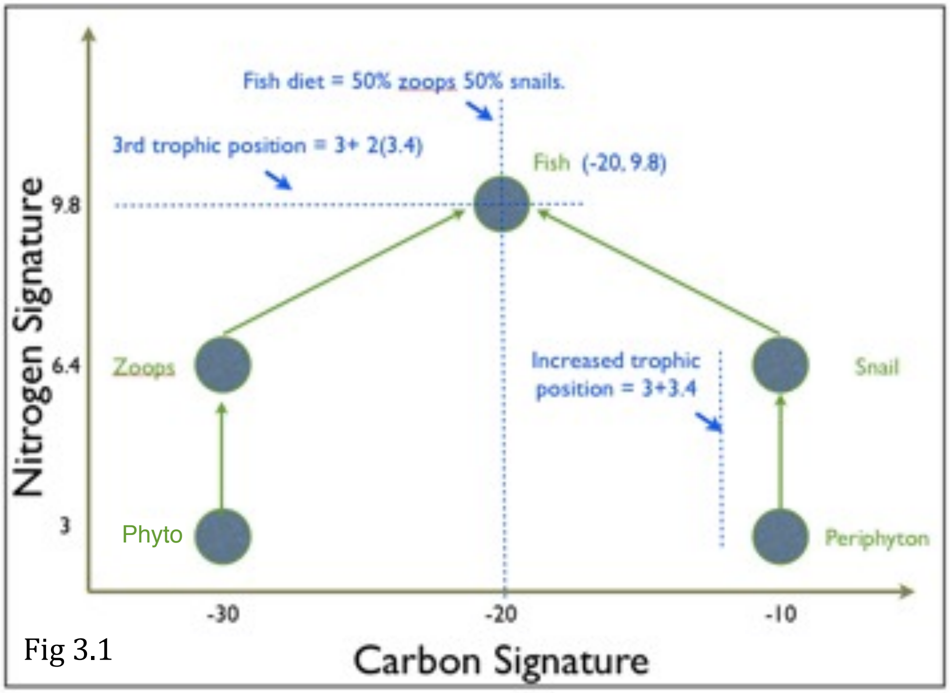

Fig 3.1


Fig 3.2 Pictures of Seining(left), D-net (top right) and Surber (bottom right).

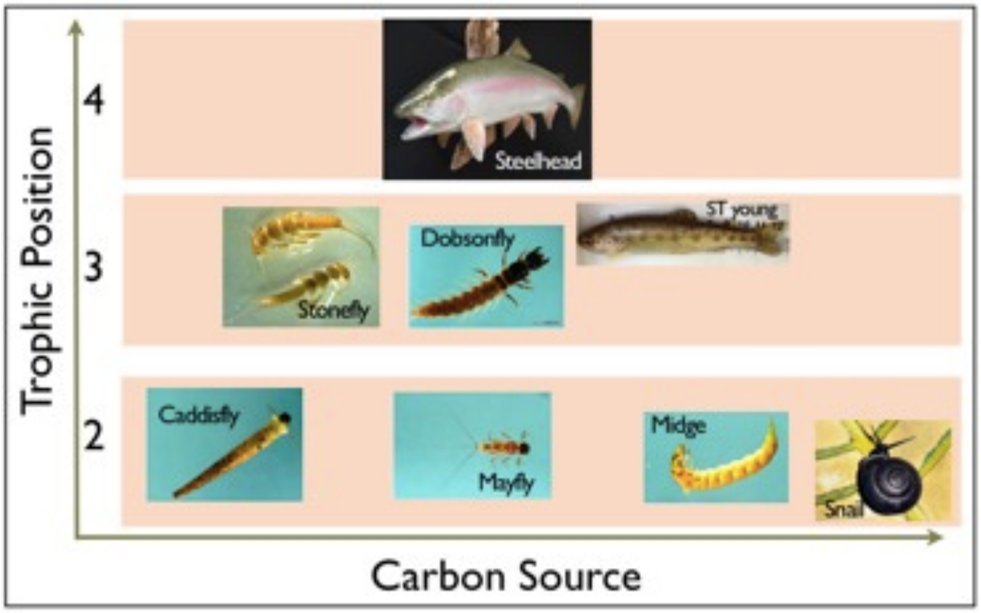

Fig 4.1 High Flow Predicted Results. The grazers, caddissflies, mayflies, midges and snails, make up the secondary trophic position. Caddissflies and mayflies consume leaf-like carbon sources and midges and snails consume periphyton. Stoneflies, dobsonflies, and steelhead young are in the tertiary trophic position. Stoneflies consumed caddisflies and mayflies. The dobsonflies' diet is mostly mayflies. The steelhead young consume the smaller invertebrates: mayflies, midges, and some snails. The steelhead adult is the top predator, at the fourth trophic position. The steelhead evenly consume stoneflies, dobsonflies and steelhead young.

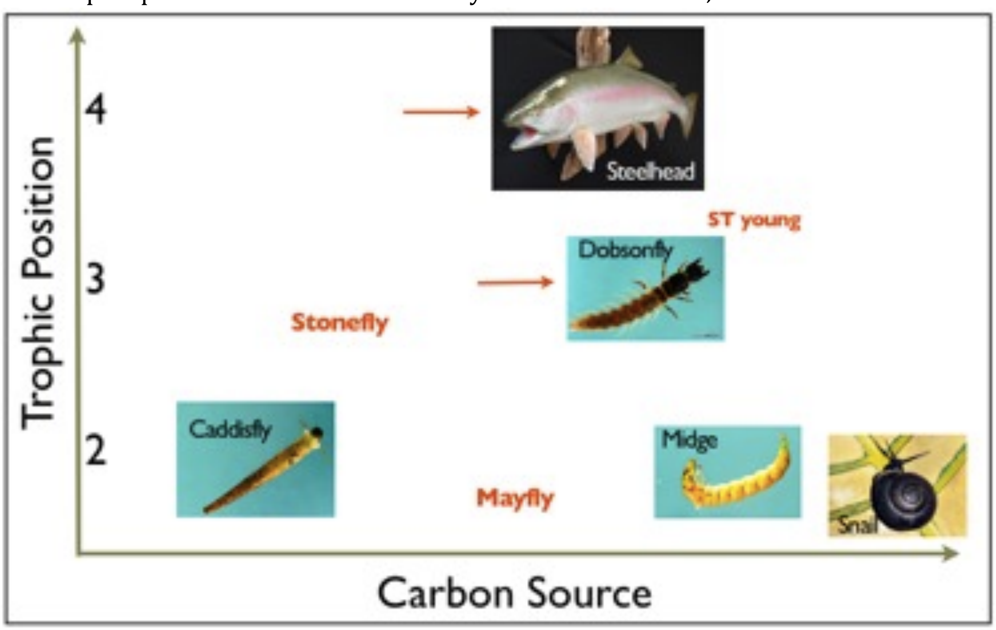

Fig 4.2 Low Flow Predicted Results. In a small isolated or nearly isolated pool the food web is expected to shift its reliance to periphyton carbon sources. The cadissfly grazers will persist until they mature and leave the pool. The snails and dobsonflies have tough protective layers to help their populations survive the environmental stresses, so they will be available for consumption. The mayfly and stonefly populations will be limited, due to predation, and so they will no longer be available for consumption. The fragile steelhead young will be eliminated due to predation and environmental stresses, and therefore will no longer be a viable food source for adult steelhead.

6.0 Discussion

The validity of the hypothesis will not be known until the isotope data has been fully processed at the UC Davis Isotope Lab. It is not clear if the hypothesized changes are correct. During the summer field collection it was noted that the drying pattern in the summer 2012 is similar to the 2009 season based on our habitat measurements.

When combined with previous year's data from the JWF, this summer's field season has contributed to a better overall understanding of the riparian fragmenting system at JWF. The average size of the steelhead young has changed between years, with the majority of the young collected this summer being too small to PIT tag. It is still unclear how the steelhead young size will impact the overall survival of the steelhead population at JWF. When collecting the steelhead at the beginning of the summer the fish seemed particularly fragile, and methods were established to limit the handling of the tiny fish. Additionally during the last few weeks at JWF many of the young steelhead were not present. It appears that the age of the fish at the time of fragmentation may play a critical role in survival although additional studies will be needed to address this question.

While the analysis of the isotopic signatures is not complete, it is possible through observation, natural history, and site history to compare this summer's research with other similar studies. For example, studies by (Layhee, 2011) and (Vander Zanden, 2003) also used stable isotopes to examine trophic structures of aquatic systems. For example (Vander Zanden, 2003) used stable isotopes to compare samples from Lake Tahoe in 2000 to samples of from the lake in 1872-1966. Their results show that the yearly isotopic signatures were not significantly different but that species-specific mean values over several years were a more accurate representation of the changes in the Tahoe basin. (Vander Zanden, 2003). In a similar manner (Layhee, 2011) compared four Hawaiian streams at various levels of disturbance to examine food web changes.

Stable isotopes are a useful tool for studies such as this because of the isotopes ability to quantify changes in the food web compared to traditional food web enumeration methods. Stable isotopes are time integrated, so each carbon and nitrogen signatures is the product of the species consumption over the recent past (month(s) depending on tissue type) Stable isotopes are also ideal for simple food webs, such as the JWF site where pools are small and isolated. In addition the ability to obtain carbon and nitrogen signatures from preserved samples allows researchers to collect tissue samples well before they are ready to be processed. In a conservation sense, stable isotope analysis is beneficial because tissue sampling at the higher trophic levels (ie fish) is non-destructive and therefore the fish survive.

One of the methods of analyzing stable isotope data is to calculate the change in area beneath the top predator over time. (Layman, 2006) If there is enough significance in the area under the steelhead trout in each pool at similar flow levels, these will be compared to address niche collapse. Food webs may also be compared by measuring the variation between each species' trophic position's distance from the center of the food web. This calculated distance is called the centroid distance (CD). (Layman, 2007 Layhee, 2011) It is not clear if the change in CD will be significant but if a change occurs we would predict that the CD would decrease as the pools dry. Decreasing CD would be additional evidence of niche collapse.

The results from this study provide a window into the relationship between decreasing water volume and resource availability as the food web changes. Additional studies will be required to understand the food web structure of riparian habitats in their entirety but this study can serve as a building block for understanding seasonal systems such as the JWF. Since the steelhead trout spends a portion of its life in this seasonal habitat understanding the functions of a riparian zone will be essential in designing programs or policies to protect the steelhead in the future.Maintaining the steelhead trout in the Lagunitas Creek system is essential to the survival of the steelhead population but also to the maintenance of ecological stream function. The removal of a top predator has the potential to cause an aquatic trophic cascade (Cain, 2011). If the top predators (trout) decrease in abundance, it would possibly cause a spike in the stonefly and dobsonfly populations. The rising stonefly and dobsonfly populations could decimate the mayfly and midge populations, which in turn may decrease the overall productivity of the stream system (Voshell, 2002).

Examining the trophic structure of the steelhead's habitat will help direct conservation efforts. Preserving the riparian habitat as well as the species that play a role in the food web will keep the steelhead trout's niche intact. The entire aquatic food web snails, midges, mayflies, and caddisflies must be maintained to support the steelhead population. In the future new methods should be designed for measuring habitat so that as new pools and riffles form over the course of the summer or years of study, the changing hydrology will be more accurately taken into account. As stated previously, the study should also be carried out over several summers. Processing the samples is a major bottleneck in this study and so additional mechanisms for processing data in the field would provide more rapid turn around of isotope data. Several frogs and salamanders were found on site but, as the permit did not allow it, we did not take tissue samples. This is potentially a drawback, because these species can be significant players in the food web. Undoubtedly this study has brought more questions than answers thus far but it is promising in its objective of increasing the understanding of function of fragmentation at JWF.

7.0 Acknowledgments

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8.0 References

Bogan, M. T. and Lytle, D. A. (2011), Severe drought drives novel community trajectories in desert stream pools. Freshwater Biology, 56: 2070–2081. doi: 10.1111/j.1365-2427.2011.02638.x

Cain, Michael L., William D. Bowman, and Sally D. Hacker. *Ecology*. Sunderland, MA: Sinauer Associates, 2011. Print.

Chang, Raymond. *Chemistry*. New York: McGraw-Hill, 1994. Print.

Hauer, F. Richard., and Gary Anthony. Lamberti. *Methods in Stream Ecology*. San Diego: Academic, 1996. Print.

James W. McClelland, Ivan Valiela and Robert H. Michener, Limnology and Oceanography. Vol. 42, No. 5, Part 1 (Jul., 1997), pp. 930-937

Jepson, Willis Linn, James C. Hickman, and Willis Linn Jepson. *The Jepson Manual: Higher Plants of California*. Berkeley: University of California, 1993. Print.

Layhee, Megan Chico State University (2011) 1-29 Employing Stable Isotopes to Investigate the Impacts of Invasive Species on Hawaiian Food Webs

Layman, Craig; Ecology Letter (2007) 10:937-944 Niche width collapse in a resilient top predator following ecosystem fragmentation

Layman, Craig; Ecological Society of America (2007) 42-48 Can stable Isotope Ratios Provide for Community-Wide Measures of Trophic Structure?

McGinnis, Samuel M., and Samuel M. McGinnis. *Field Guide to Freshwater Fishes of California*. Berkeley, CA: University of California, 2006. Print.

Primack, Richard B. *Essentials of Conservation Biology*. Sunderland, Mass., U.S.A.: Sinauer Associates, 1993. Print.

Voshell, J. Reese. *A Guide to Common Freshwater Invertebrates of North America*. Blacksburg, VA: McDonald & Woodward Pub., 2002. Print.

Zanden, M.Jake; PNAS (2005) 102:20 pp. 7055-7056 The success of animal invaders

Zanden, M.Jake; Chandra Sudeep; Ecosystems (2003) 6:274-288 Historical Food Web Structure and Restoration of Native Aquatic Communities in the Lake Tahoe Basin

Zanden, M.Jake; The American Naturalist (1999) 154:4 pp406-416 Patterns of Food Chain Length in Lakes: A Stable Isotope Study

Images:
Fig 1. "A Natural Sanctuary." *Pt. Reyes National Seashore*. National Park Service Dept of the Interior, n.d. Web. 13 July 2012. <http://www.nps.gov/pore/index.htm>.

Fig 4. "North Atlantic Area Products and Services." *North Atlantic Area Products and Services*. N.p., n.d. Web. 08 Aug. 2012. <http://www.ars.usda.gov/Services/docs.htm?docid=15744>.

Fig 6. Clark, Jack. "Biting Midge Larva." *Biting Midge Larva*. Science Photo Library, n.d. Web. 08 Aug. 2012. <http://www.sciencephoto.com/media/370052/enlarge>.
Novak, George. "Austrosimulium-Sandfly-larvae-04." *Flickr*. Yahoo!, 08 Dec. 2010. Web. 08 Aug. 2012. <http://www.flickr.com/photos/georgenovak/5243008961/in/photostream/>.