Macroinvertebrate Community Structure in Streams Affected By Conventional and Organic Cranberry Cultivation

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Abstract
Cranberry farming is the most important form of agriculture in Cape Cod Ma. (Cape Cod Cranberry Growers Association). This study aims to assess the affect of conventional and organic cranberry farming practices on macroinvertebrate community structure in the waterways flowing through two active and one abandoned cranberry bog. In stream macroinvertebrate communities were sampled in one conventionally managed bog, one organically managed bog and one long-abandoned bog. The data collected were used to assess species diversity and abundance, as well as food web structure. Species diversity was greatest in the abandoned bog, followed by the organic and conventional bogs. The greatest macroinvertebrate biomass was found in the Organic bog, followed by the conventional and abandoned bogs. The % N addition retained in the food web was greater in the organic bog than the conventional bog. This N sequestration in the bog food web has the ability to mediate the amount of N leaving the bog each year. These findings recommend wider adoption of organic cranberry agriculture in Cape Cod.

Introduction
Cranberry based agriculture has been an important part of Southeastern Massachusetts’ economy and culture for the last 200 years (Cape Cod Cranberry Growers Association). Cranberries grow on low-lying bush-like vines that may be as long lived as 150 years. Traditionally, cranberry bogs are built with a system of waterways, which are used for irrigation and flooding of the wide flood plain on which the cranberry bushes grow. The water for these bogs is generally sourced from pre-existing streams or ponds and pumped through the bog as needed. Water generally leaves cranberry bogs in the form of small streams.

Conventional cranberry agriculture is typified by the heavy use of fertilizers and pesticides to produce a profitable amount of production. Organic farming practices aim to produce cranberries using fewer fertilizers and pesticides, creating an agricultural system that more closely mimics nature. Organic cranberry producers utilize the ability to flood bogs as a pest control mechanism.
Where a conventional grower may only flood their bog for harvest and to prevent freezing. An organic grower may flood the bog for long periods, several times a year to drown pests.

Macroinvertebrates are a useful subject for this study because they act as environmental indicators in streams (Hauer and Lamberti, 2006). Also, they take up a variety of trophic levels and functional groups, so they can act as accurate indicators of food web function. Furthermore, are relatively easy to quantitatively sample.

I am interested in whether the use of conventional or organic cranberry farming is a significant control on stream macroinvertebrate species diversity, abundance, and food web structure. I hypothesized that macroinvertebrate communities will be less species diverse in the conventional plot than in the organic or control plot. If the conventional plot were less species diverse than the control then it would exhibit a food web with fewer filled niches.

**Methods**

**Sites**

Three cranberry bogs were chosen as sites for this study. The sites include one conventionally farmed bog, one organically farmed bog, and one bog that has been in restoration for about 80 years, which acts as a control. The conventional bog is called Beaton’s Pierceville bog located in Wareham Ma. The Organic Bog is called Cape Farm and Cranberry Company and is located in Harwich Ma. The farm is certified organic. The control site is a bog in Falmouth Ma, which has been in restoration for about 80 years. At each Site, samples were taken from three sub-sites; one at the head of the bog, one near the middle of the bog, and one in the woods in the bog’s outflow stream. At the control bog, since the entire area we considered was evenly wooded we chose three evenly spaced sub-sites. Sampling in these sites occurred between the dates of November 12 and 15, 2013.

**Invertebrate Sampling**
Three quantitative samples of macroinvertebrates were collected at each sub-site using a surber sampler (Hauer and Lamberti, 2006). Depletion sampling was employed so an accurate estimate of biomass could be acquired. The quadrat on the surber sampler is 961 cm². With the net in the water, all rocks in the quadrat were rubbed clean of anything on them, and the sediment below was disturbed, allowing loose insects to be washed into the net. The contents of the sampler were put in labeled plastic bags and placed in a cooler and refrigerator at 4°C until they could be processed. Sampling was performed, moving sequentially upstream so as not to disturb any invertebrates upstream and incur double counting. Once the first set of samples were taken in each sub-site, sampling was performed twice more in the same places to make sure that the established quadrats were reasonably depleted. In the lab, the samples were put through a 1 mm and a 63µm sieve. The invertebrates were separated from detritus and sand in the sieves and identified as close as possible to species level. Samples were dried in a 51°C oven for about 48 hours to prepare them for weighing and grinding for 13C and 15N stable isotope analysis. The dry mass was taken of each species combined from each sub-site.

Qualitative Sampling

To frame the food web for stable isotope analysis, possible macroinvertebrate food sources including vegetation and particulate organic matter were sampled. To determine the food web structure, any available primary production was qualitatively sampled and stored in plastic bags at 4°C in a cooler and freezer. Since many macroinvertebrates acquire food by picking organic matter out of the water column, it was necessary to include Particulate Organic Matter (POM) as a possible energy source in the stable isotope analysis. To sample Particulate Organic Matter, a 1L bottle of stream water was collected from each macroinvertebrate sampling site. The bottles were kept in a cooler and freezer until further processing. Water samples were then filtered through ashed 25 mm GFF filters until the filters were completely saturated. The filters were then dried in a 51°C oven for about 48 hours. The entire filters were sent for 13C and 15N stable isotope analysis.
\(^{13}\)C and \(^{15}\)N Stable Isotope Analysis

Representative macroinvertebrate and vegetation samples from each system were chosen for \(^{13}\)C and \(^{15}\)N stable isotope analysis. Macroinvertebrate samples included 2 to 6 of the dominant species from each system. Primary producer samples included every species of vegetation collected. Samples were made up of all dried members of each species combined into one cumulative sample and ground together via mortar and pestle.

Food Webs and Mixing Model

From the results of the stable isotope analysis, partial food webs were constructed for each system. Using the package, SIAR in statistical the analysis program, R, each invertebrate was mixed with 3 primary producer sources. Based on the stable isotope data, the primary producers that were collected were broken down into 3 groups to act as the sources in the mixing model. The three sources were enriched N C3 plants, depleted N C3 plants and algae. A k-means cluster analysis was used to determine the centroid of each of these groups. Using SIAR, the proportion of each of these sources that each consumer was composed of was determined. The results of the mixing model were used to determine the trophic level of each consumer. The fraction of each source was multiplied by that source’s \(\delta^{15}\)N, and then multiplied by the consumer’s \(\delta^{15}\)N divided by the assumed trophic N fractionation of 3. This provided the trophic level of each species sent for stable isotope analysis.

Scaling Up

To get an understanding of how the presence of a macroinvertebrate community differently affects the amount of added Nitrogen leaving each of the two in production bogs each year I established a model. The amount of yearly fertilization per acre, as well as the % N of the fertilizer was obtained. This was converted to g N m\(^{-2}\) y\(^{-1}\). The area of macroinvertebrate habitat in the whole of each bog was estimated using a combination of satellite Imagery and field measurements
of channel length and width. Using the following equation (Banse and Mosher 1980), the P/B for Invertebrates in each system was calculated.

Equation 1
\[
\log(P/B) = -0.19 + 0.37 \times \log(\text{Dry Weight})
\]

The average P/B for all of the systems was then used to estimate macroinvertebrate production in each active bog. The average %N for macroinvertebrates that was used for stable isotope analysis was used to convert production to g N/y. Nitrogen required for primary production was back-calculated by multiplying macroinvertebrate production by mean trophic level divided by the N trophic transfer efficiency calculated by (Iverson 1990). The Primary production of N was divided by the total amount of N added each year. This provided us with the % N addition retained in the bog-channel food web.

Results

Diversity and Abundance
At each site, a net depletion of macroinvertebrate biomass was achieved by the third depletion run (Figure 1). Macroinvertebrate biomass was greatest at the organic site, followed by the conventional site and the control site with values of 0.0068, 0.0066 and 0.0032 g C/m² respectively (Figure 2). The greatest number of species was found at the organic site at 16, followed by the control at 14 and the conventional at 12. Simpson diversity index was greatest at the control site at 4.7, followed by the organic and the conventional at 4.1 and 1.5, respectively (Figure 3). Species diversity was much more similar between the organic and control sites than the conventional (Figure 3). Very clear species dominance was exhibited at the conventional site, with Isopods making up more than 80% of macroinvertebrates identified (Figure 4). The control and organic sites exhibited much less extreme species dominance, with the most dominant species taking up 32% and 43% of species found respectively (Figures 5 and 6).
Food Webs and Mixing Model

In the food web for the conventional site, there were two distinct trophic levels, with *Isopods* making up the lower consumers and *Hirudinea* making up the higher consumers (Figure 7). However, in the organic and control sites, the trophic structure is less obvious. In the organic site, there was a grouping of 3 lower consumers (*Isopods, Amphipods* and *Chloeoptera*), 1 mid-level consumer (*Decapods*) and 2 higher consumers (*Hirudinea* and *Anisoptera*) (Figure 8). In the control site, the trophic groupings included lower consumers (*Amphipods* and *Tipulida*) and higher consumers (*Trichoptera* and *Hirudinea*) (Figure 9).

Preliminary food web results indicated that the conventional and organic sites were missing a depleted δ¹³C source, so the algae from the control site was used for the mixing model in the conventional and organic sites. In all cases, calculated trophic level was much lower than expected, with many consumers below 1. However, calculated trophic level did make sense when higher and lower consumers were compared relatively. Mean trophic level was significantly higher in the control site than in the organic or conventional site. There was no significant difference in mean trophic level between the organic site and conventional site (Figure 10).

Scaling Up

A total of 36128, 20411 g N/y were added to the conventional and organic bogs, respectively. 1713, 2064 g N/y were used in stream channel primary production in the conventional and organic bogs. This translated into 5% of the added N being taken up in the conventional macroinvertebrate food web and 13% of the added N being taken up in the organic macroinvertebrate food web.
Discussion

Diversity and Abundance

Macroinvertebrate biomass was greatest in the two actively farmed sites. This shows that the amount of primary production is also much greater in the actively farmed sites. If the in production bogs have greater macroinvertebrate biomass, then it is likely that agricultural runoff allows for more primary production in the system, and therefore a larger food web. If Nitrogen is a limiting nutrient in these systems, then we can assume that fertilization may facilitate bottom up control of the cranberry bog food web. Increasing N addition can explain 76% of the increase in macroinvertebrate biomass (Figure 11). This agrees with findings previous research in that macroinvertebrate production increases as N inputs increase (Shieh et al 2002).

Although they were more productive, macroinvertebrate communities in the active bogs were less diverse than the control. It is expected that macroinvertebrate communities are less diverse along an increasing gradient of anthropogenic disturbance (Allan 2004). It is likely that the lack of diversity in the conventional site is due to its relatively heavy use of pesticides. Although there is a large amount of biomass, only a few generalist species are hearty enough to withstand the insecticides used. Species diversity has been shown to enhance ecosystem stability (Tilman 1996). Greater species diversity in the organic site may allow for better ecosystem stability, and thus more reliable nutrient processing on the long term.

This study asserts that organic farming enhances species abundance in the sites that were studied. However, across a wide range of studies, conclusions are often less clear. Hole et al 2005 state that the study of particular practices will be more informative than general system-level studies which cannot give more explanation distinguish beyond an organic, conventional classification.

Food Webs and Mixing Model

The control and organic food webs show a much greater amount of niche diversity and redundancy than the conventional. Niches are diverse because The
food webs are redundant because more than one organism takes up the same trophic position in the same site (Figure 8, 9). It is likely that this niche diversity and redundancy allow for the system to run leaner and allow fewer resources to escape without recycling. More diverse systems may also be more resilient to short term pulse disturbances because if one species rapidly declines in a diverse system, another species will likely be able to fill its niche and continue the ecosystem function facilitated by those in that niche (Eby et al 2006). Whereas, in a very simple system with each trophic level dominated by one species, if one species is removed, there can be drastic consequences throughout the system.

It is expected that the control site would exhibit a significantly greater mean trophic level than either of the in-production sites because it presumably has the least N addition. Therefore the Nitrogen in the control system has undergone many more trophic transfers than in either of the agricultural systems. I expect that if every organism in each system were used for the stable isotope analysis, as opposed to just the ones selected, the mean trophic level in the organic site would be greater than was found. If all found organisms were considered, the greater diversity in the organic would likely raise the mean trophic level because of a greater relative proportion of +1 trophic level consumers. However, nutrient addition may not always lead to an increase in the highest consumers (Abrams 1992). A solid understanding of the feeding behavior of mid level consumers would be necessary to predict how the system would react to increased production. Also, likely top consumers in these systems, such as frogs, fish and birds were not surveyed. An understanding of the size of these populations would allow for a better estimate of mean trophic level for each system.

Mean trophic level was much lower than made sense in every site except for the control site. This can be attributed to the fact that an alga from the control site was used to mix every other site for lack of any other suitably δ^{13}C depleted sources in those locations. This alga was very δ^{15}N enriched, likely because of a greater amount of nutrient recycling in the control site. That erroneously decreased the calculated trophic level of each consumer in the other sites. To avoid this issue in future studies, it will be important to sample a wider variety of in-stream primary
production to make sure that each site has what it needs to be mixed. Also, sampling primary producers and macroinvertebrates throughout the year will be imperative so we know that what we are proposing that the macroinvertebrates are made of is what they actually were eating as they matured. For instance, Primary producers in the conventional bog are more δ^{15}N enriched at the time of year that the sampling was done than during the growing season because their N sources at that time were very depleted N fertilizer.

Scaling Up

Based on the model calculation, the food web of the organic bog keeps 8% more of the yearly N fertilizer addition within the cranberry bog. This can be attributed to larger area of macroinvertebrate habitat and smaller yearly N addition in the bog. However, if diversity were more directly accounted for in this model, it is likely that the difference between the conventional and organic bog would have been greater. That raises a case for very limited pesticide use in these systems. 13% does not initially sound like a very large N sink, but if we removed the N in the harvested cranberries from the equation, the relative proportion of N sequestered in the bog food web would be greater.

Conclusions

This data presented in this study make a strong case for the environmental benefits of organic cranberry farming. Not only are fertilizer additions smaller, but also the biotic systems that are built into the structure of the agricultural system are more able to keep whatever nutrients are added on site as opposed to being carried downstream where they can cause a variety of problems. Also, it is very possible that these systems are more stable, so this function is maintained even through periods increased disturbance. Organic cranberry agriculture serves as an encouraging compromise between maintaining the local agricultural heritage and preserving imperiled freshwater stream systems on Cape Cod.
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Literature Cited


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Figures

Figure 1: Depletion curve for each site
Figure 2: Macroinvertebrate Biomass at each site

Figure 3: Simpson Diversity Index at each site
**Figure 4:** % total abundance at the control site
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\[ R^2 = 0.7629 \]