

**The epibenthic community observed in association with  
the intensive raft culture of *Mytilus galloprovincialis* in Totten Inlet, Washington**

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**Abstract.** The epibenthic community sympatric with cultured *M. galloprovincialis* was periodically inventoried over a one-year growout of *Mytilus galloprovincialis* in Totten Inlet, Washington State. The community was found to be diverse and abundant with seasonal changes in dominant taxa. Species richness, abundance, Shannon's Index and community biomass increased exponentially throughout the year with maximum values of each endpoint observed in the last sample collected in November just before the cultured mussels were harvested. Community differences were observed when comparing raft center stations with perimeter stations. The biomass of commensal organisms represented 20% of the biomass of mussels at harvest on the perimeter of the rafts and 5.3% of the mussel biomass in the center of the line of six rafts. The high species richness observed was hypothesized to result from significant differences in physicochemical attributes of the habitat created by the mussel lines with an inner matrix of sulfidic organic material supporting an array of deposit feeders gradually changing to a well flushed perimeter that was dominated by filter feeding organisms. The farm produced 726,400 kg of cultured mussels in 2002 and at harvest the commensal community was estimated at 92,253 kg or 172.5 kg/m<sup>2</sup>. This large biomass of non-cultured organisms represents a food resource for fish and other predators. In eutrophic bodies of water, removing the commensal community with the cultured mussels at harvest will remove additional nitrogen, ameliorating excess nutrient loading. However, if the commensal community is returned to the water during harvest, it could exacerbate benthic effects and this could diminish beneficial nitrogen removal.

**1.0. Background.** Mussel lines (Figure 1) provide a complex habitat and are typically fouled with a variety of plants and animals. These naturally occurring assemblages of organisms that take up residence amongst the cultured mussels also consume phytoplankton and organic detritus; consume oxygen; and they produce and remove metabolic waste. Therefore they are an integral part of the living reef created on mussel rafts. This study quantifies the epibenthic community growing sympatrically with raft cultured mussels in Totten Inlet, Washington over a single production cycle.

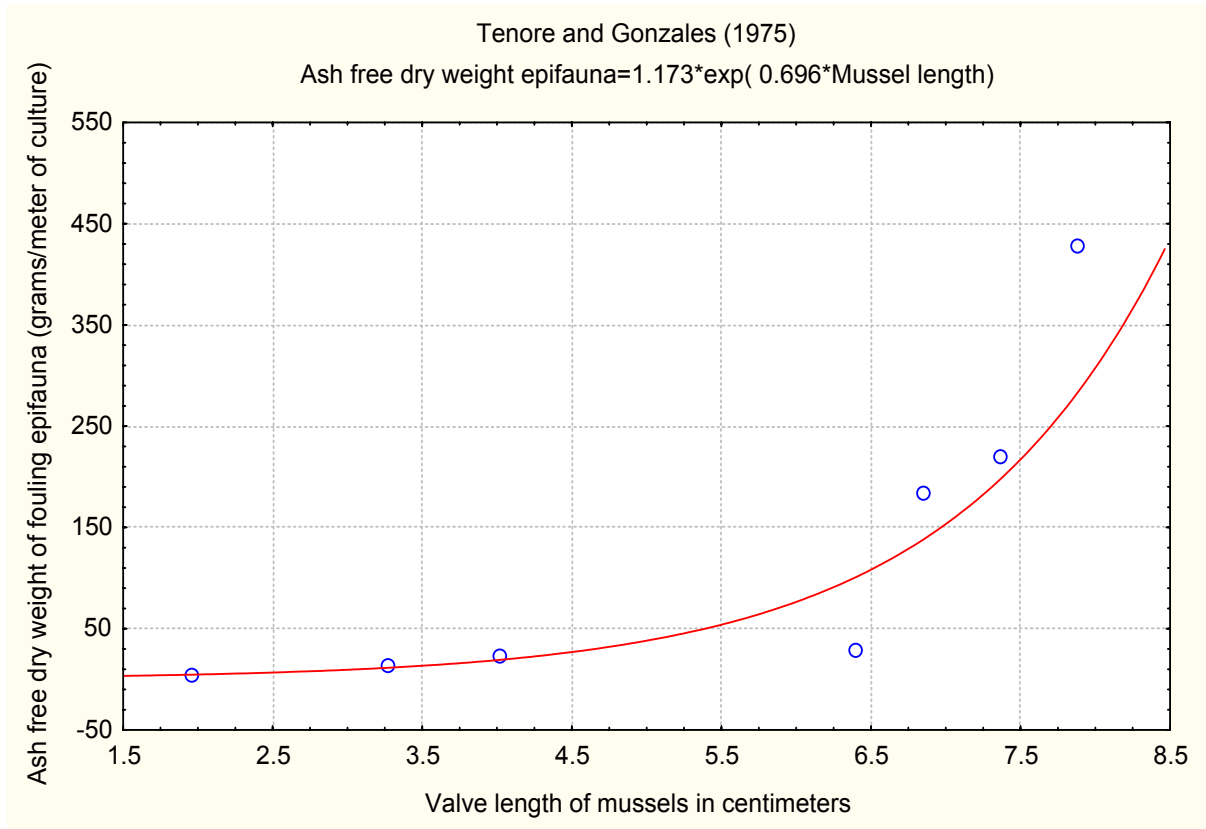


**Figure 1. Raft cultured *Mytilus galloprovincialis* and their commensal invertebrate community.**

The habitat created by mussel cultures is composed of three levels: (1) a physical matrix of interconnected living and dead mussel shells; (2) an inner core of accumulated biodeposits that includes mussel feces and pseudofeces, organic detritus, and shell debris that supports a diverse community of deposit feeding organisms; and (3) an outer layer of living mussels with an often diverse community of epibionts (Suchanek, 1979; Mattsson and Linden, 1983). The benthos underlying suspended bivalve cultures receives biodeposits from the cultures and their symbionts. The environmental response of the benthos is very different from that of the invertebrate community resident within suspended mussel cultures. Therefore, these two environmental compartments will be addressed separately. Seed and Suchanek (1992) reviewed the literature describing the sympatric community associated with naturally occurring aggregations of mussels. The diversity of invertebrate fauna in mussel beds was typically high and variable with 12 to 135 taxa present in single samples. Suchanek (1979) found a total community of 300 taxa in 12 invertebrate phyla and three species of bony fish living sympatrically in *Mytilus californianus* beds on the coast of Washington State. Mussel bed communities are typically dominated by three phyla; including annelids (worms), arthropods (amphipods, crabs, etc.) and other mollusks (other bivalves like *Hiatella arctica* and gastropods including nudibranchs). This diversity is created because mussel communities, including those growing on raft cultures offer a broad spectrum of habitat types that are suitable for a number of trophic levels. The community associated with hanging mussel cultures in Penn Cove included large numbers of caprellids (2 to 3 cm long amphipods that look like a preying mantis), sea cucumbers (*Eupentacta quinquesemita*), solitary ascidians, and annelids such as mussel worms (*Nereis vexillosa*). These mussel rafts also attracted schools of shiner perch (*Cymatogaster aggregata*) that fed on the associated invertebrate community (Brooks, unpublished). There is a striking similarity between the fouling community observed in Penn Cove and that documented by Tenore and Gonzalez (1975) on mussel rafts in the Ria de Arosa on the coast of Spain just north of Portugal. The estuary covers approximately 250 km<sup>2</sup> and supports exceptionally high biomasses of intensively cultivated mussels. Production was estimated at 160,000 metric tons total wet weight of mussels per year by Tenore and Gonzalez (1975). This is equivalent to a density of ca. 640 grams wet tissue weight/m<sup>2</sup>, which is three times higher than the proposed density of 206 g/m<sup>2</sup> in Totten Inlet (total bivalve culture of 5,085 metric tones (whole wet bivalve weight) divided by an area 24.71 km<sup>2</sup>). Because of its long history of high mussel production, the Ria de Arosa has been the subject of numerous studies examining the environment's response to intensive mussel culture. The epifaunal community growing sympatrically on mussel cultures was found by Tenore and Gonzalez (1975) to vary with mussel size and season. In September 1974, this community included over 100 species. The ash free dry weight (TVS) of epifauna (excluding sea stars) varied between  $4.14 \pm 0.76$  g TVS/meter of rope culture for small mussels in June, 1974 to  $429.45 \pm 115.19$  g TVS/meter for larger mussels. High correlation coefficients were found in this database between epifaunal biomass and either mussel valve length ( $r = 0.79$ ) or mussel dry tissue weight ( $r = 0.76$ ). Figure (1) describes a non-linear least squares derived fit to the data. The equation predicts a total epifaunal community equal to 13.4 grams (ash free dry weight) per meter of mussel culture during the mid point in mussel growth (~3.5 cm valve length). Tenore and Gonzales (1975) partitioned the symbiont data by major taxa. Of those taxa, seed mussels, Platyhelminthes (flat worms), Polychaeta (annelid worms), and Crustacea (amphipods, crabs, etc.) were considered fish prey items. The ash-free dry weight of each of these major taxa are also included in Figure (2) provides a

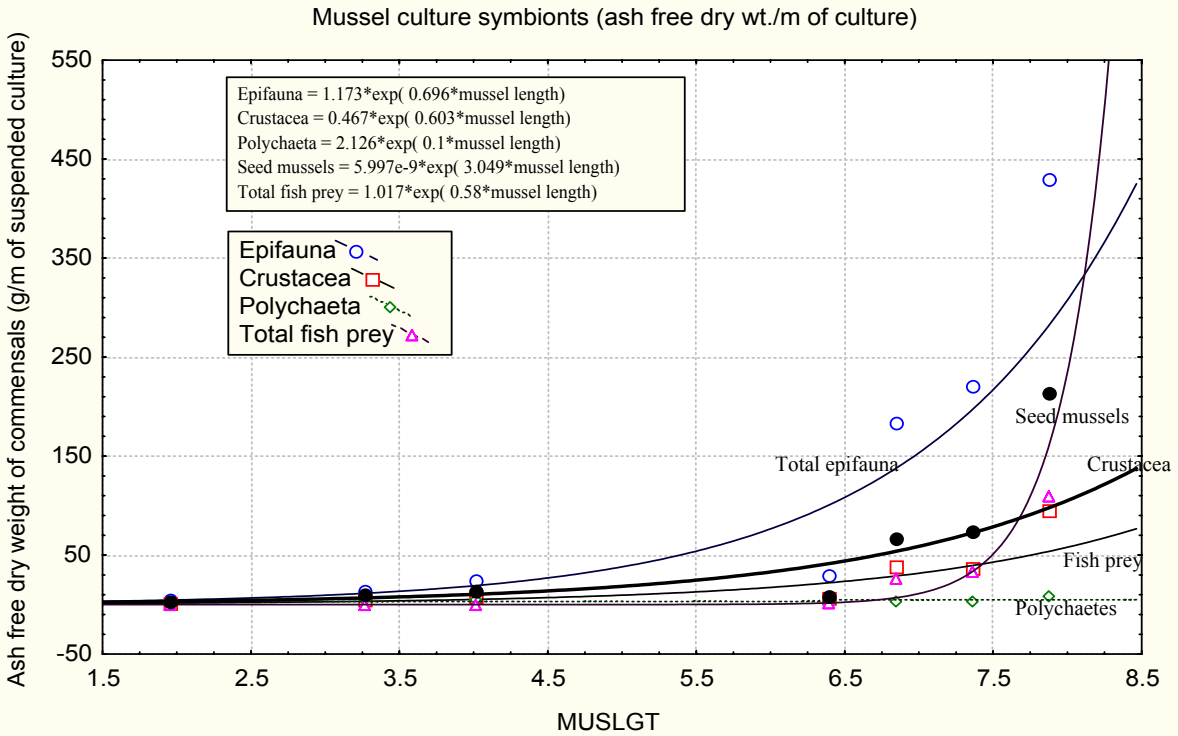
nonlinear (exponential) fit predicting the ash-free dry weight of each class of symbionts as a function of the cultured mussel valve length.

The biomass of fish prey/m<sup>2</sup> raft area is given in Figure (3). Mussel rafts in the Ria de Arosa covered an average area of 400 m<sup>2</sup> and each raft held an average of 700 culture lines that were 8 m in length. The total length of culture per raft was therefore 5,600 m and each raft contributed approximately 75 kg TVS of epifauna to the environment – equivalent to 375 kg wet weight. The biomass of fish prey associated with these rafts was 100 g TVS/m<sup>2</sup> of raft, equivalent to approximately 200 kg of invertebrate prey species/raft at the mid point (3.5 cm) in the mussels' growout.

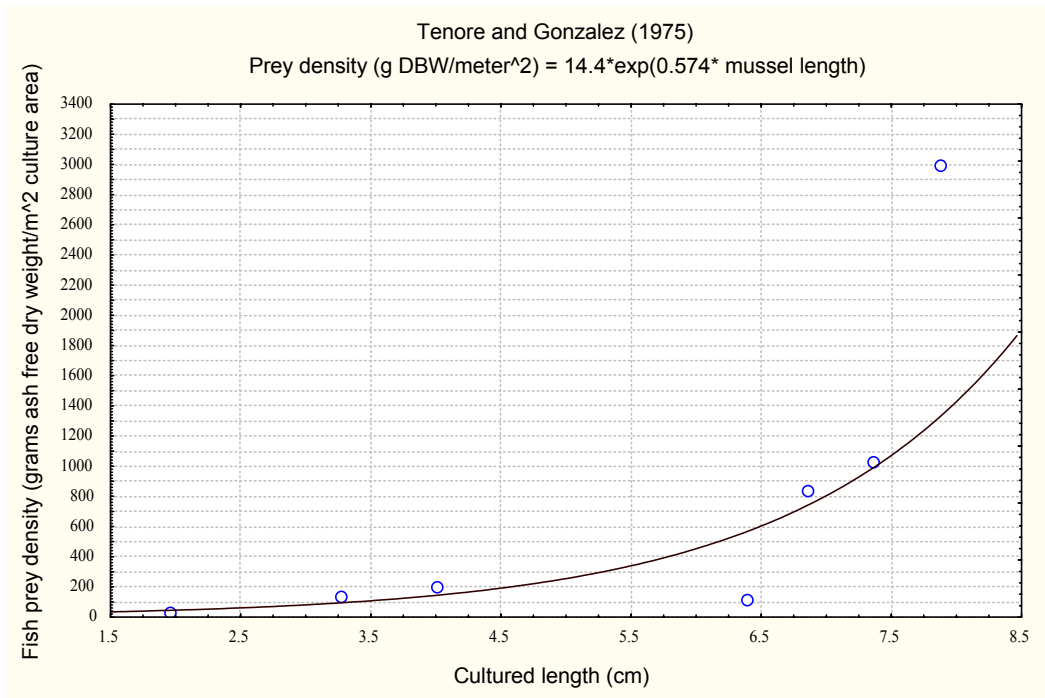


**Figure 1. Ash free dry weight of symbionts growing on mussel culture lines in the Ria de Arosa, Spain (Tenore and Gonzalez, 1975).**

Tenore and Gonzalez (1975) found significant fecal and pseudofecal deposits in the inner core of the mussel lines. The symbionts associated with newly established cultures containing small mussels were generally detritus feeders (70%) as opposed to suspension feeders (3.6%). In contrast, older cultures (larger mussels) were dominated by suspension feeding symbionts (67.7%) rather than detritivores (26.6%). Tenore and Gonzalez (1975) hypothesized that a significant amount of the waste was processed on the mussel lines by symbionts rather than falling to the benthos. This caused invertebrate production in the vicinity of the rafts to shift from the benthos to the mussel lines. Lopez-Jamar *et al.* (1984) also found that mussel culture diminished the contribution of benthic infauna to fish diets, but that fish shifted to the more abundant epifauna associated with the suspended cultures.

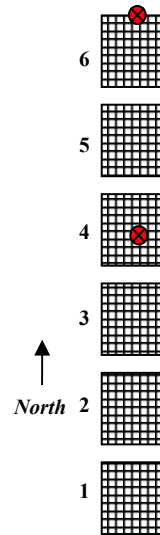


**Figure 2. Ash free dry weight of major taxa growing on mussel culture lines in the Ria de Arosa, Spain (Tenore and Gonzalez, 1975).**



**Figure 3. Predicted fish prey (seed mussels, Platyhelminthes, Polychaeta and Crustacea) observed on hanging mussel culture reported by Tenore and Gonzales (1975). Data have been converted to grams ash free dry weight of prey items per square meter of raft.**

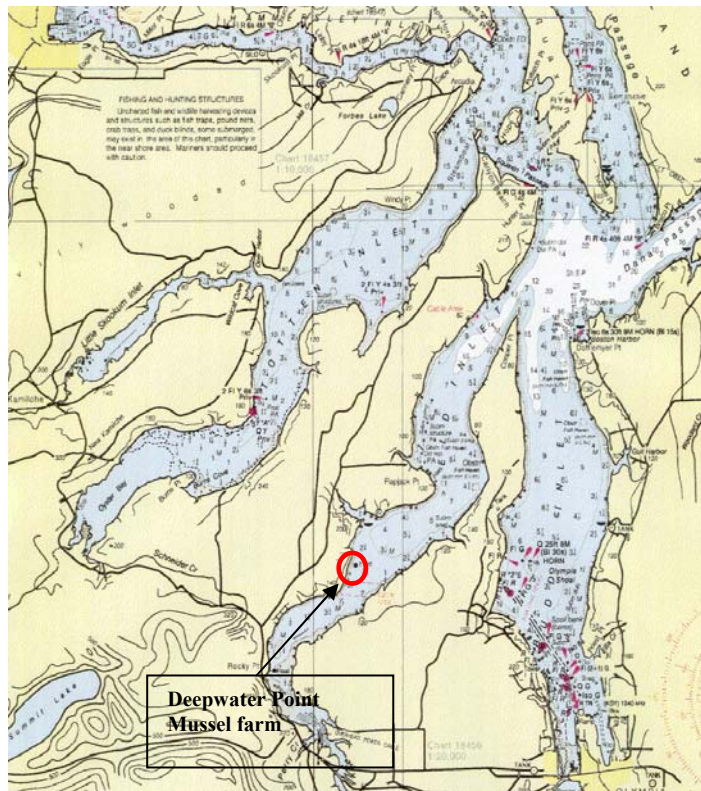
**2.0. Methods.** Mussel lines were retrieved from three depths at the center and on the perimeter of the six raft array anchored closest to shore at the Deepwater Point farm (red locations in Figure 4). The mussel lines were laid out on the rafts' decks and 30 cm sections removed at depths of 0.3, 1.5 and 3.0 m. Each section was placed in a separate 5-gallon bucket. This provided six samples during each sample period. The fouling community was assessed on March 30, July 8 and November 22, 2002 giving a total of 18 samples. All fouling organisms were washed from the mussels using 100  $\mu$ m filtered seawater. The material washed from the mussel lines was sieved on 500  $\mu$ m stainless steel screens; fixed in 10% borax buffered formalin for four days; and then preserved in 70% isopropyl alcohol. Macrofauna were picked from the background matrix using *Leica* M3Z stereo microscopes. Ten percent of the samples picked by each technician were repicked by a second technician. A sorting efficiency of 95% was required in compliance with PSEP (1996). Macrofauna was identified to the lowest practicable level – generally to species. The nomenclature used is that of Kozloff (1987), Abbott (1974), Hobson and Banse (1981) and Banse and Hobson (1974). All taxa were compared with verified specimens in Aquatic Environmental Science's (AES) reference collection or will be verified by another taxonomist at some point in the future. Samples were archived at AES for a period of at least three years.



**Figure 4. Relative location of mussel line samples from the Deepwater Point farm in Totten Inlet**

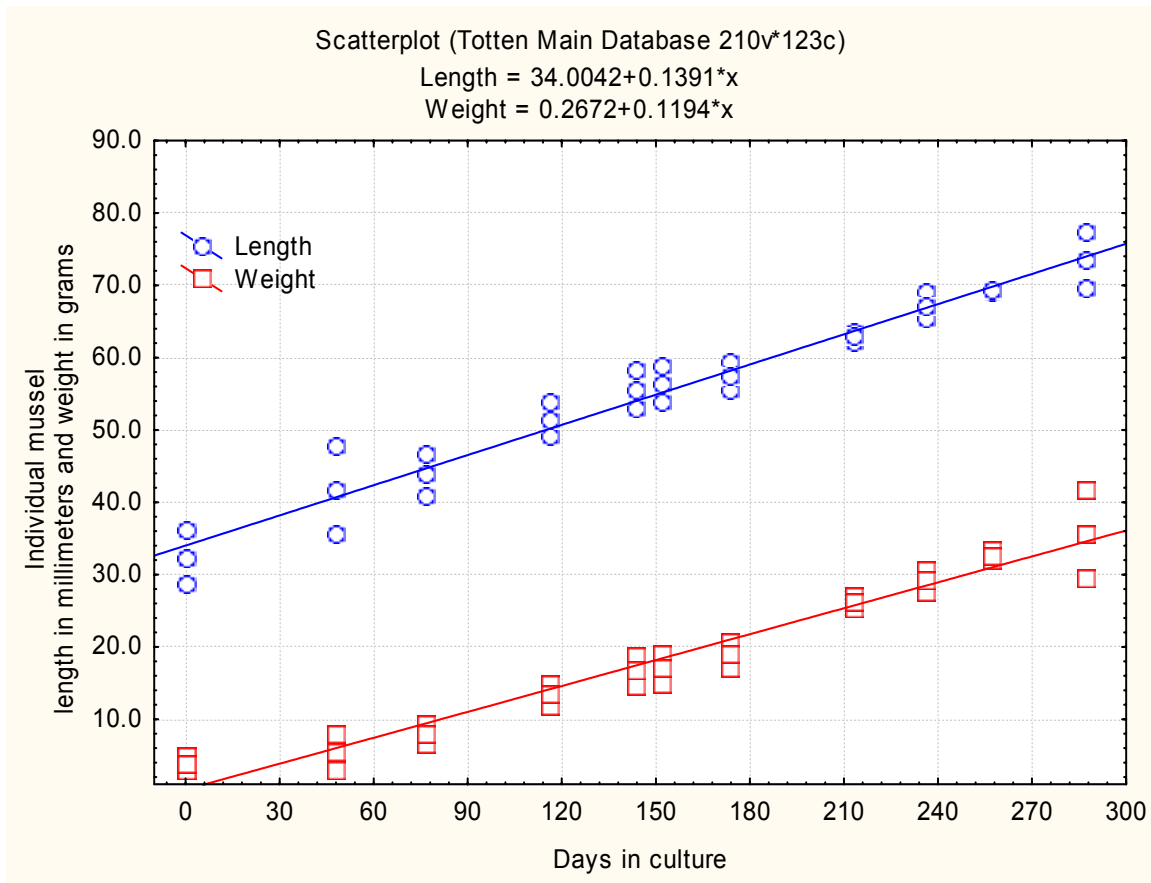
The washed mussels were held on ice in an insulated cooler until blotted dry and weighed on an American Scientific Products Model B1240 four place balance the next day. The length of each mussel was measured to the nearest 0.01 mm using Starrett® model 721 digital calipers. A total of 1,568 mussels were collected, weighed and measured. Data was entered into a Microsoft™ Excel® spreadsheet for preliminary analysis and then imported into Statistica™ Version 6 software for statistical analyses.

**3.0. Results.** Taylor Resources Deepwater Point mussel farm is located in Totten Inlet a tributary of Puget Sound in Washington State (Figure 5). The farm is comprised of 48 rafts arrayed in 8 rows of six rafts each. Each raft measures 9.14 x 9.75 m, covers 89.15 m<sup>2</sup>, and supports 720 culture lines that are 4.6 m long. There are 4,320 lines on the six rafts,

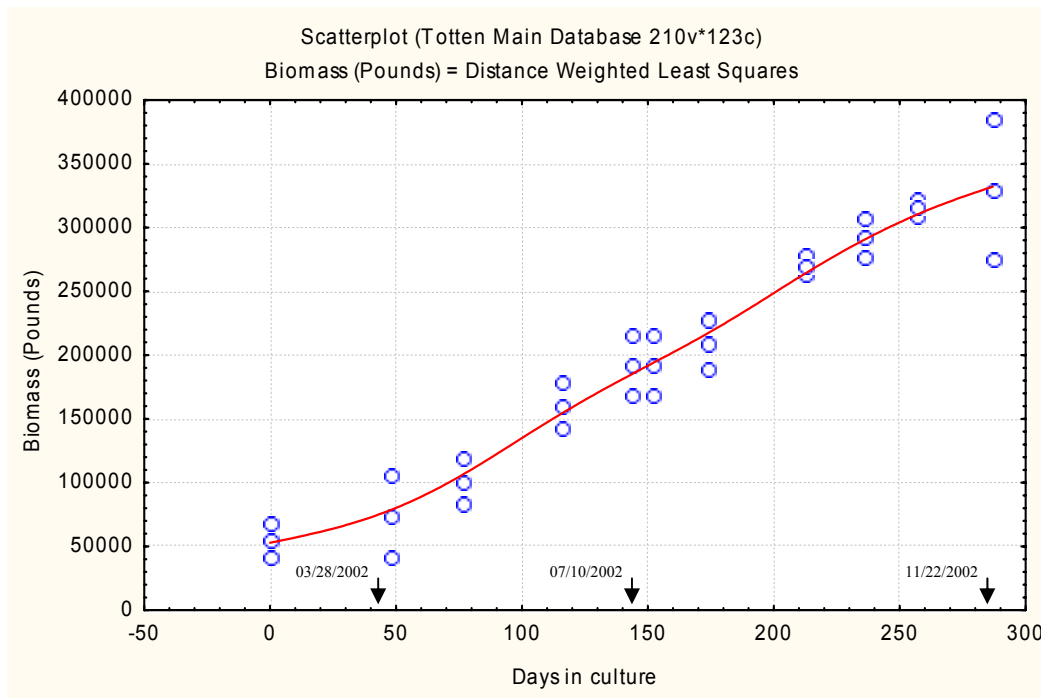


**Figure 5. Site diagram describing the location of the Deepwater Point mussel farm in Totten Inlet, Puget Sound, Washington**

which cover an area of 534.9 m<sup>2</sup> in association with this row. Mussels on rafts one through 6 were seeded at 1,400/line on or about December 15, 2001 at valve lengths of 1.5 to 2.0 cm. Survival was not rigorously determined, but based on historical production records survival is estimated at 65% from seeding to harvest following 12 to 14 months of growout. Approximately 85 percent of the 48 rafts are used each year to produce 1,600,000 pounds of live mussels (727,272 kg/yr). Figure 6 summarizes the length of the mussel cohort, as a function of time, using data developed in this study, supplemented with additional unpublished data supplied by the Pacific Shellfish Institute. Figure 7 estimates the biomass of mussels growing on the inner row of rafts as a function of time assuming 65% survival of the seed. The epibenthic community sampling dates are highlighted. These dates were chosen to correspond with season (early spring; summer; and late fall) and mussel biomass (small, intermediate and large). The cultured mussels appear to have been in the exponential growth phase throughout the production cycle with no significant indication of seasonal affects on growth or of spawning. Raft 4 produced 18,886 kg and Raft 6 produced 23,634 kg of mussels. A total of 137,713 kg were harvested from this line of 6 rafts between December 1, 2002 and February 5, 2002.



**Figure 6. Length and weight of *M. galloprovincialis* as a function of days in culture in Totten Inlet, Washington State.**



**Figure 7. Estimated biomass of *M. galloprovincialis* growing on the inner row of rafts where the epibenthic community was assessed. Epibenthic community sample dates are highlighted.**

**3.1. Epifaunal community.** A total of 14,698 animals and 106 taxa were identified in the 18 samples. Twenty-four of the taxa were found in an abundance  $\geq 1.0$  percent of the total abundance on each sample day. Colonial animals such as sponges (Phylum Porifera), bryozoans, hydroids and etc. were present on and after July 8, 2002. They were not included in the abundance because their numbers would be extremely difficult to quantify. They were included in the biomass measurements and in determining the number of taxa in each sample. An inventory of those taxa representing at least 1.0% of the total abundance on each sample day is provided in Table 1. These 24 taxa accounted for 88.3% of the total abundance. Six of the dominants were arthropods; 11 were annelids; five were mollusks; and the other two were cnidarians (anemones) and nematodes. Table 2 provides summary statistics describing each of the samples. A complete inventory is provided in Appendix 1. Note that the most abundant mollusk was the Olympia oyster (*Ostrea conchaphila*) that set sometime in late July or August and were dominant on November 22, 2002. These oysters set sometime after the July 8, 2002 samples were collected. Brooks (2000) summarized the life history of this species and noted that published reports indicate that ovigerous females have been observed in South Puget Sound from mid-May until late July. The larvae are brooded for 10-12 days in the anterior branchial chamber of the female prior to being released in an advanced veliger stage. Further development as a component of the plankton is expected to take 10 to 23 days at the 19 – 22 °C temperatures expected in Totten Inlet during summer. This suggests that larvae spawned in late July would settle as late as the end of August. While the specific life history of the small native oysters observed living sympatrically with the mussel cultures is unknown, their size suggests they likely

settled sometime after the end of August 2002. It should also be noted that relatively high densities of living native oysters were observed on the perimeter and in the center of Raft 4 – suggesting that the larvae survived equally well in the interior and on the perimeter of the rafts, which were dominated by filter feeding mytilids.

**Table 1. Summary statistics describing taxa representing at least 1.0% of the total macrofaunal abundance observed on mussels lines at the Deepwater Point farm in Totten Inlet, Washington. Abundance is the aggregate for six 30 cm length segments of mussel growout line collected on each sample day. Mollusks are highlighted in blue, arthropods in red, annelids in green and other taxa in black.**

Taxon	3/20/2002	7/08/2002	11/22/2002
Juvenile Caprellidae	1774	33	76
<i>Chtamalus dalli</i>	0	1494	128
<i>Corophium salmonis</i>	70	37	581
<i>Caprella gracilior</i>	261	12	57
Other barnacle species or juveniles	147	3	0
<i>Metacaprella kennerlyi</i>	128	13	11
<i>Ostrea conchaphila</i>	0	0	523
Juvenile Mytilids	72	40	518
<i>Odostomia tenuisculpta</i>	5	46	397
Juvenile <i>Modiolus sp.</i>	20	258	329
<i>Hyatella arctica</i>	0	32	205
<i>Ophiodromus pugettensis</i>	45	82	355
<i>Nereis juveniles</i>	493	311	482
<i>Schistomeringos annulata</i>	12	13	418
<i>Paleanotus occidentale</i>	196	57	157
<i>Polydora socialis</i>	0	281	29
<i>Micropodarke dubia</i>	149	36	122
<i>Hesionidae juveniles</i>	77	17	153
Unidentified juvenile annelids	105	50	91
<i>Capitella capitata</i>	7	110	119
<i>Antinoella macrolepida</i>	4	73	85
<i>Armandia brevis</i>	131	13	11
<i>Telea and Metridium sp.</i>	410	348	515
Nemertians	20	14	112

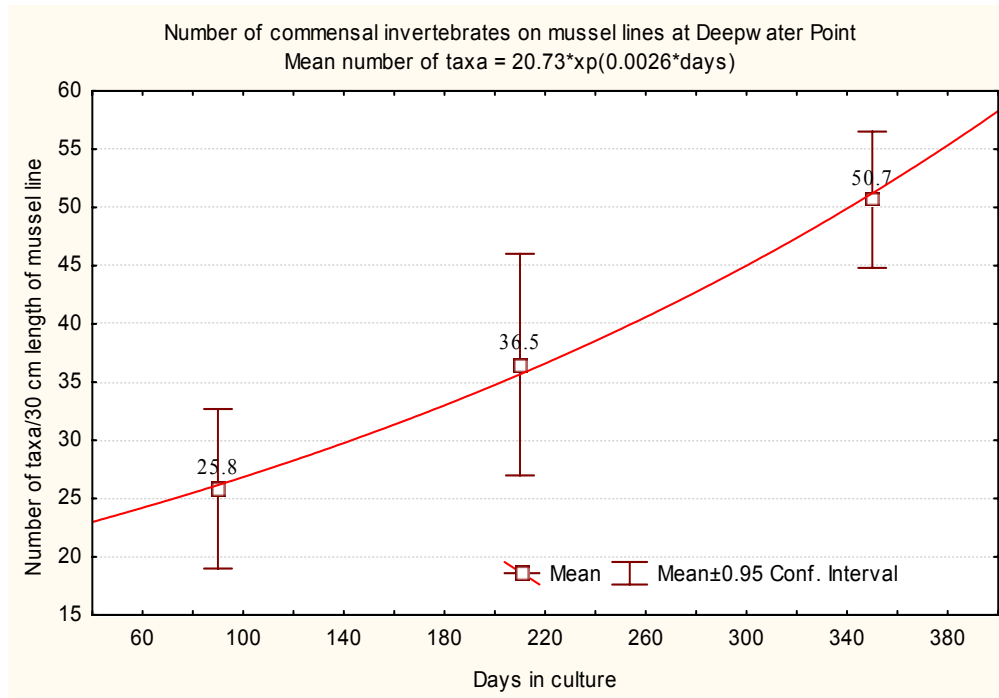
*Species richness and diversity.* The number of taxa/sample as a function of the age of the culture is provided in Figure 8. Differences in richness as a function of location were apparent in summer. However, the differences were not significant and linear regression predicts that the number of taxa increased linearly at a rate equal to  $13.1 + 0.101 \cdot \text{Days in culture}$  ( $R^2_a = 0.69$ ).

Shannon's index is summarized in Figure 9. The communities diversity was dominated by caprellids in the spring of 2002. As this species died out in summer, diversity increased exponentially reaching values  $>2.6$  by mid summer. The high diversity observed in the late fall of 2002 likely reflects the increasing diversity of the mussel line habitat created as the cultures matured.

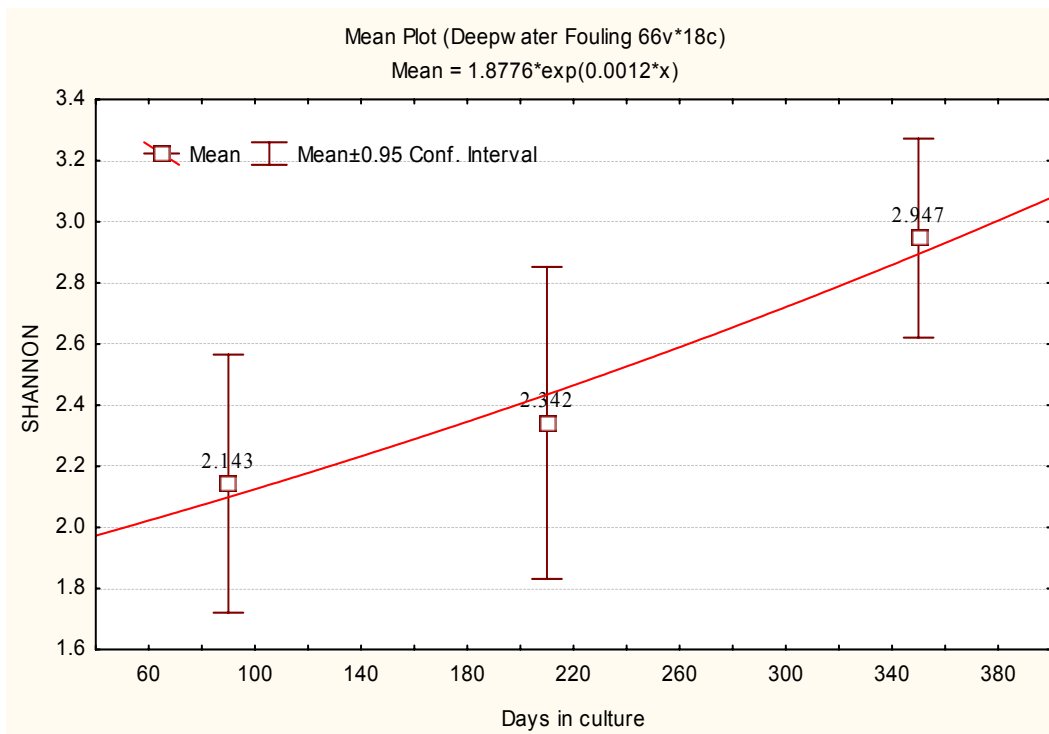


**Table 2. Summary statistics describing the abundance, number of taxa and wet weight of macrofauna per 30 cm of mussel line at the Deepwater farm located in Totten Inlet, Washington. Shannon's and Pielou's indices are also provided for each sample.**

					ABUNDANCE	TAXA	WET WEIGHT	SHANNON	PIELOU
Deepwater	3/20/2002	C	0.3	1	1903	28	15.3	1.501	0.45
Deepwater	3/20/2002	C	1.5	1	363	20	3.1	1.968	0.65
Deepwater	3/20/2002	C	3.0	1	397	24	6.2	2.145	0.67
Deepwater	3/20/2002	P	0.3	1	373	23	6.5	2.465	0.79
Deepwater	3/20/2002	P	1.5	1	815	38	21.4	2.656	0.73
Deepwater	3/20/2002	P	3.0	1	546	22	28.2	2.122	0.69
		Total for six samples			<b>4397</b>		<b>80.8</b>		
Deepwater	7/8/2002	C	0.3	1	562	39	119.4	2.735	0.75
Deepwater	7/8/2002	C	1.5	1	736	35	39.0	2.123	0.60
Deepwater	7/8/2002	C	3.0	1	946	52	21.9	2.838	0.72
Deepwater	7/8/2002	P	0.3	1	1007	37	98.7	1.509	0.42
Deepwater	7/8/2002	P	1.5	1	280	25	25.7	2.541	0.79
Deepwater	7/8/2002	P	3.0	1	331	31	388.6	2.305	0.67
		Total for six samples			<b>3862</b>		<b>693.4</b>		
Deepwater	11/22/2002	C	0.3	1	1420	56	132.8	3.122	0.78
Deepwater	11/22/2002	C	1.5	1	625	55	75.6	3.426	0.85
Deepwater	11/22/2002	C	3.0	1	466	42	81.6	3.025	0.81
Deepwater	11/22/2002	P	0.3	1	1602	55	469.3	2.809	0.70
Deepwater	11/22/2002	P	1.5	1	1029	48	268.5	2.746	0.71
Deepwater	11/22/2002	P	3.0	1	1297	48	563.3	2.552	0.66
		Total for six samples			<b>6439</b>		<b>1591.2</b>		
					<b>14,698</b>		<b>2,334</b>		

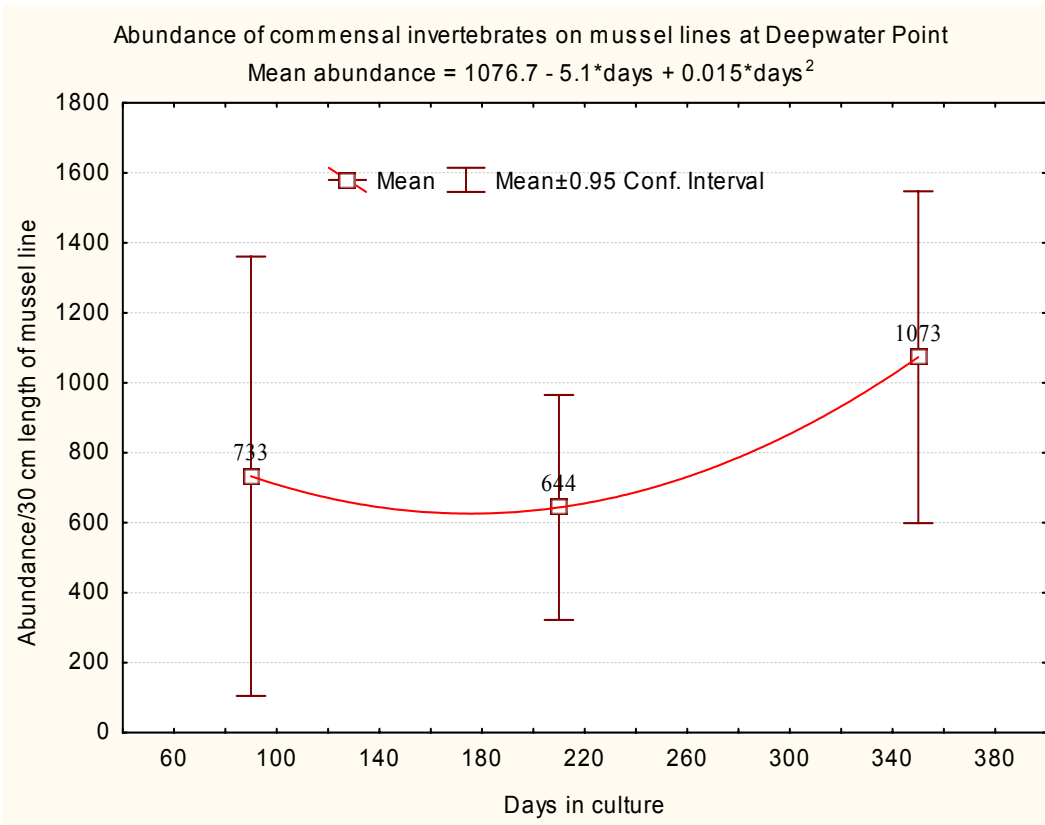


**Figure 8. Species richness observed on cultured mussel lines at the Deepwater Point mussel farm in Totten Inlet Washington during a single growout period in 2002.**



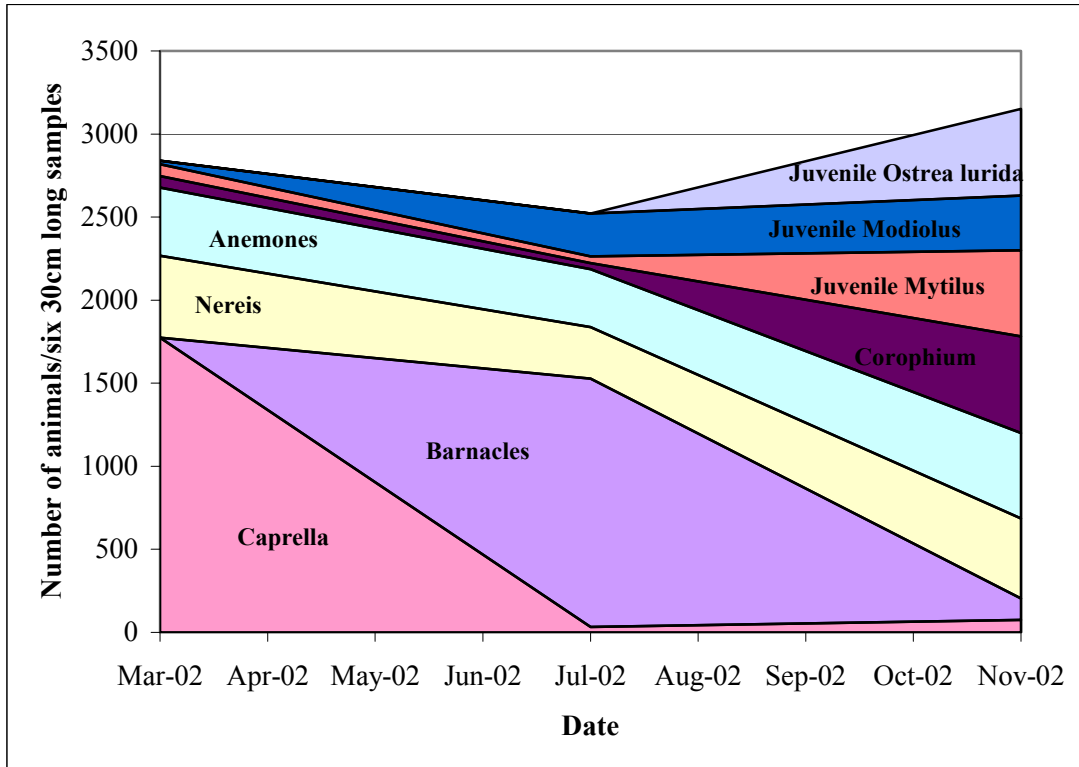
**Figure 9. Shannon's index in 30 cm long samples of the commensal macrofaunal community growing on mussel lines in 2002 during production of *M. galloprovincialis*. Triplicate samples were collected at each of three depths on three sample days.**

*Abundance of symbionts.* The abundance of macrofauna identified on 30 cm long sections of mussel line is summarized in Figure 10. The abundance was relative constant during the first 205 days of culture and then increased during the latter portion of the growout.



**Figure 10. Invertebrate abundance in 30 cm long samples of the commensal macrofaunal community growing on mussel lines in 2002 during production of *M. galloprovincialis*. Triplicate samples were collected at each of three depths on three sample days.**

*Community composition.* The eight taxa that each represented  $\geq 3.6$  percent of the overall abundance are summarized by sample in Table 3 and Figure 11. Caprellids and barnacles appear ephemeral and died out in summer and early winter after setting in the spring. This life history is observed at many finfish and shellfish aquaculture facilities in the Pacific Northwest (Brooks unpublished). The abundance of mollusks (*Ostrea conchaphila*, *Modiolus sp.* and juvenile *Mytilus*) increased gradually from mid summer to the end of the study as did the abundance of the amphipod *Corophium salmonis*. Anemones and nereids recruited early and were a stable part of the community throughout the production cycle.

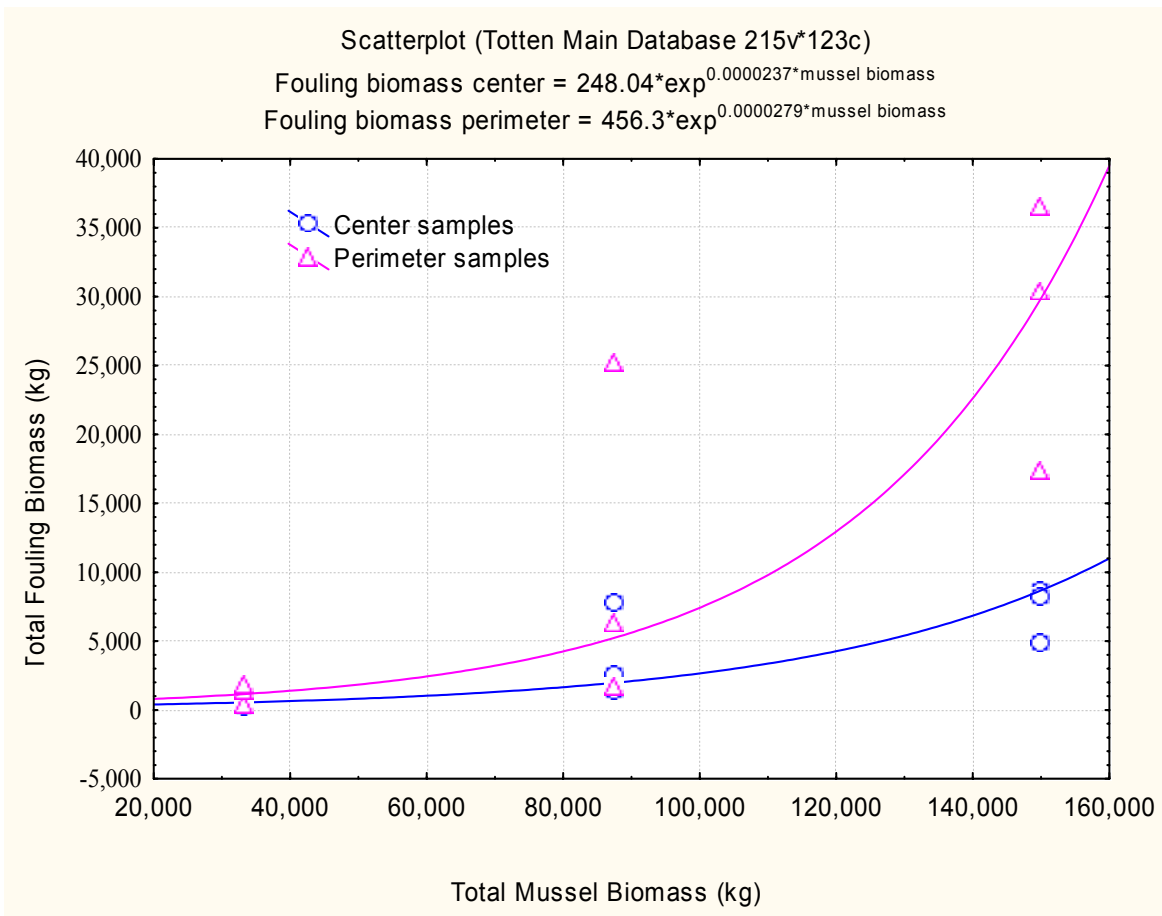


**Figure 11. Abundance of the eight taxa representing  $\geq 3.6\%$  of the total abundance of macrofauna living sympatrically on cultured mussel lines at the Deepwater Point farm in Totten Inlet, Washington.**

**3.2. Epifaunal community biomass.** The biomass of commensal invertebrates on the mussel lines was estimated by assuming that there were 4,320 lines on the six rafts in this row and that each line was 4.59 m long. The wet tissue weight of epifauna recorded for each 0.30 m long sample was then multiplied by  $4.59 \times 4,320 / 0.30 = 66,096$  and divided by 1000 g/kg to estimate the epifaunal biomass in kilograms. It should be noted that the biomass (weight or volume) of fouling organisms was dominated by anemones in July and November. Figure 12 describes the relationship between the biomass of cultured mussels and that of the commensal community. The null hypothesis that epifaunal biomasses were equal at all depths was not rejected. However, location and date were significant factors at  $\alpha = 0.05$  with increasing epifaunal biomass as a function of time and with higher biomasses recorded on the perimeter in comparison with the center of the rafts. Epifaunal biomass represented only 2.6% of the mussels' biomass in April 2002 after 7 months of culture. This is in part due to the December 15, 2001 seeding date which is late in the invertebrate recruiting season in Puget Sound (Strathmann 1987). On the perimeter of the culture, the proportion of the system's biomass attributable to non-cultured epifauna increased exponentially to 5.7% in July and to 20% in November 2002 following 11 months in culture. Epifaunal wet biomass also increased exponentially in the center of the line of 6 rafts; but not as quickly reaching only 5.3% of the mussel biomass by the end of the production cycle.

**Table 3. Summary statistics describing the abundance of the eight most dominant taxa observed growing sympatrically with cultured *Mytilus galloprovincialis* in Totten Inlet, Washington State during 2002. All values are number of organisms per 30 cm length of cultured mussels.**

	Location	Depth (m)	<i>Caprella</i>	Barnacles	<i>Nereis</i>	Anemones	<i>Corophium</i>	<i>Mytilus</i>	<i>Modiolus</i>	<i>Ostrea conchaphila</i>
3/20/2002	C	0.3	1221		159	13	61	54	11	
3/20/2002	C	1.5	152		13	12		3	0	
3/20/2002	C	3.0	134		24	6		7	0	
3/20/2002	P	0.3	13		74	82		1	4	
3/20/2002	P	1.5	125		151	141	9	2	5	
3/20/2002	P	3.0	129		72	156		5		
Total by taxon and sample date			1774	0	493	410	70	72	20	0
7/8/2002	C	0.3	2	20	100	136	4	7	14	
7/8/2002	C	1.5	5	368	59	16	6	5	51	
7/8/2002	C	3.0	11	266	67	19	21	7	98	
7/8/2002	P	0.3	15	686	22	63	2	13	62	
7/8/2002	P	1.5		68	19	21	4	6	30	
7/8/2002	P	3.0		86	44	93		2	3	
Total by taxon and sample date			33	1494	311	348	37	40	258	0
11/22/2002	C	0.3	1		182	81	30	81	53	72
11/22/2002	C	1.5	7	3	43	1	20	16	7	45
11/22/2002	C	3.0	1		29	22	3	0	1	0
11/22/2002	P	0.3	1	121	12	107	173	331	67	223
11/22/2002	P	1.5		2	13	53	38	68	192	159
11/22/2002	P	3.0	66	2	203	251	317	22	9	24
Total by taxon and sample date			76	128	482	515	581	518	329	523



**Figure 12. Comparison of the biomass of fouling organisms on the abscissa with the biomass of cultured mussels on the ordinate.**

**3.3. Inferential tests.** Table 4 summarizes a multifactor analysis of variance for the major biological endpoints evaluated in this study. All count data were  $\ln(N+1)$  transformed prior to the analysis. Macrofaunal abundance was not significantly different as a function of Date, Location or Depth. The Number of Taxa and Shannon's Index were significantly influenced only by Date with the number of taxa and the diversity of the community slowly increasing with time. None of these collective endpoints were a function of depth in the water and only Wet Sample Weight was significantly a function of location.

Table 5 provides the results of an analysis of variance assessing the effects of Date, Location and Depth on the categories "Other," "Annelids," "Mollusks," and "Crustaceans." Crustacean abundance was not significantly different as a function of any of these independent variables. Mollusks and Annelids were significantly affected only by Date and animals in *Other* phyla, dominated by anemones, were significantly affected only by location. Following the first sample period, a significantly higher biomass of organisms (particularly anemones) was observed on the perimeter of the raft when compared with the raft's center (see Table 3).

**Table 4. Summary results of a multifactor analysis of variance assessing differences in macrofaunal abundance, number of taxa, Shannon's index and sample wet weight as a function of sample Date, Location (raft center or perimeter) and Depth below the surface of the water (0.3, 1.5 or 3.0 m).**

Univariate Tests of Significance for LABUNDANCE (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1605.886	1.000	1605.886	2541.689	0.000
Date	2.191	2.000	1.095	1.734	0.218
Location	0.010	1.000	0.010	0.016	0.903
Depth	2.254	2.000	1.127	1.784	0.210
Error	7.582	12.000	0.632		

Univariate Tests of Significance for LTAXA (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	486.299	1.000	486.299	5149.893	0.000
Date	2.818	2.000	1.409	14.922	0.001
Location	0.036	1.000	0.036	0.378	0.550
Depth	0.055	2.000	0.027	0.289	0.754
Error	1.133	12.000	0.094		

Univariate Tests of Significance for LWEIGHT (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	559.966	1.000	559.966	569.915	0.000
Date	67.571	2.000	33.785	34.386	0.000
Location	5.157	1.000	5.157	5.249	0.041
Depth	7.015	2.000	3.507	3.570	0.061
Error	11.791	12.000	0.983		

Univariate Tests of Significance for SHANNON (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	110.449	1.000	110.449	589.312	0.000
Date	2.103	2.000	1.052	5.611	0.019
Location	0.077	1.000	0.077	0.411	0.533
Depth	0.149	2.000	0.074	0.397	0.681
Error	2.249	12.000	0.187		

**Table 5. Main factor ANOVAs assessing the significance of differences in Ln(N + 1) transformed abundance data for a) other taxa; b) annelids; c) crustaceans; and d) mollusks observed growing in sympatry with cultured mussels on the Taylor Resources farm at Deepwater Point in Totten Inlet, Washington during 2002.**

Univariate Tests of Significance for LOTHER (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	690.646	1.000	690.646	558.273	0.000
Date	4.043	2.000	2.021	1.634	0.236
Location	6.289	1.000	6.289	5.084	0.044
Depth	1.901	2.000	0.951	0.768	0.485
Error	14.845	12.000	1.237		

Univariate Tests of Significance for LANNELIDA (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1143.357	1.000	1143.357	2329.459	0.000
Date	4.507	2.000	2.253	4.591	0.033
Location	0.128	1.000	0.128	0.261	0.619
Depth	0.355	2.000	0.178	0.362	0.704
Error	5.890	12.000	0.491		

Univariate Tests of Significance for LCRUSTACEA (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	927.665	1.000	927.665	258.954	0.000
Date	7.018	2.000	3.509	0.980	0.404
Location	0.083	1.000	0.083	0.023	0.882
Depth	1.050	2.000	0.525	0.147	0.865
Error	42.988	12.000	3.582		

Univariate Tests of Significance for LMOLLUSKA (Deepwater Fouling) Sigma-restricted parameterization Effective hypothesis decomposition					
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	550.416	1.000	550.416	139.790	0.000
Date	41.836	2.000	20.918	5.313	0.022
Location	0.119	1.000	0.119	0.030	0.865
Depth	24.873	2.000	12.437	3.159	0.079
Error	47.249	12.000	3.937		

**4.0. Summary and Discussion.** Brooks (2001a, 2001b), Brooks, *et al.* (2002), Brooks and Mahnken (2003a, 2003b), and Brooks (2003a, 2003b) have described the biological and physicochemical response to enrichment by labile aquaculture waste. This work has focused on understanding the relationship between physicochemical variables, including free sulfides, TVS and redox potential, and the macrobenthic community. Numerous taxa, including *Capitella capitata*, *Schistomeringos annulata*, *Metridium senile*, *Armandia brevis*, *Odostomia sp.*, *Alia gaussipauta*, and other taxa have been observed in anaerobic sediments near salmon farms, some



proliferating in great abundance. Other taxa have been excluded from sediments when sulfide concentrations reached several hundred  $\mu\text{M}$ . Those who have worked with cultured mussels are aware that the biodeposits formed in the center of the mussel lines become increasingly sulfidic as the cultures mature. It is likely that the increase in sulfide concentrations affects invertebrates in these communities in much the same way as it affects the macrobenthos. However, in mussel cultures there appears to be a distinct and steep cline in the accumulation of biodeposits from high in the center to very low on the periphery. Therefore it is likely that invertebrates see a range of sulfide concentrations. In addition to the proliferation of sulfide tolerant taxa seen in this study (*Schistomeringos annulata*, *Capitella capitata*, *Armandia brevis* and *Hyatella arctica*), many of the observed taxa were sensitive to even slight increases in sulfide (*Polydora socialis*, *Ostrea conchaphila* and *Corophium sp.*). These observations support the hypothetical chemical complexity of the environment created in shellfish cultures and is likely at least partly responsible for the high diversity observed. To put the term *high diversity* into perspective, many if not most macrobenthic communities in reference areas of Puget Sound are characterized by communities representing 24 to 90 taxa/0.1 m<sup>2</sup> grab sample (WDOE 1996). At the end of 342 of culture, a mean of 50.7 taxa were identified in 30 cm long sections of the mussel lines. These results demonstrate that mussel cultures present mesocosms that are ripe for exploration to unravel the intricacies of biogeochemical processing of labile aquaculture waste and of the associated biological response.

Consistent with other reports, the commensal invertebrate communities growing on the Totten Inlet mussel lines increased in species richness, abundance and diversity as the cultures matured. Their biomass at any point in time during a production cycle at Deepwater Point can be estimated using the algorithms provided in Figure 12. Significant differences in the biomass of commensal organisms are predicted as a function of location with lower fouling biomass in the center of the rafts and higher biomasses on the perimeter. The commensal community resident on the perimeter of the rafts represented 20% of the biomass of cultured mussels at the end of the growout, whereas the commensal biomass in the center of the rafts was four times lower at 5.3% of the mussel biomass. The average of the two is 12.7%. Extrapolating this to the annual production of 726,400 kg of mussels predicts an additional maximum commensal community biomass of 92,253 kg for the entire farm and it was 38,523.2 kg or 71.4 kg/m<sup>2</sup> for the evaluated row of rafts. Some of this community represents food prey for fish. All of the community consumes detritus and other forms of POM and recycles organic matter and inorganic nitrogen within the environment. In eutrophic environments, where nitrogen removal is an important benefit of shellfish culture, removal and disposal of commensal organisms during harvest can further help control nutrients. This attribute would be lost if the commensal community is removed in-situ and returned to the water. Assuming the waste settles to the bottom, this practice would exacerbate the effects of benthic enrichment reported by Brooks (2005). Commensal communities resident on mussel cultures will likely vary from one site to another. However, their biomass should be considered in evaluating beneficial and detrimental environmental effects and in development risk management strategies for intensive bivalve culture.

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