

Effects of a commercial mussel *Mytilus edulis* lay on a sublittoral, soft sediment benthic community

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ABSTRACT: A commercial mussel *Mytilus edulis* lay was established in 1998 in western inner Swansea Bay (Wales, UK) in a shallow, sublittoral, high tidal energy environment, on a substrate which previously supported a diverse inshore, sand/muddy sand benthic community. Within a year of commencement of this fishery, a significant change in the species composition of the benthic community occurred, with a decrease in the number of species and in the total number of individuals. The abundance of carnivorous and deposit feeding benthic species increased, whilst the mussels out-competed other benthic filter feeding organisms, preventing the settlement of these organisms by ingestion of the larvae, and removed other benthic organisms by physical smothering.

KEY WORDS: Mussel lay · Benthos · Community effects · Coastal waters

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INTRODUCTION

Mussels *Mytilus edulis* L. are of growing commercial importance, with increased numbers of applications for permission to site commercial mussel lays around the UK coast in shallow, sheltered, inshore environments. This method involves relaying small 'seed' mussels, taken from natural beds, onto sites (lays) where growth conditions are good and fishing by dredging is more efficient because of depth, substrate type and proximity to a port. Since the mussel seed are under fishable size a 'Several Order' has to be obtained from the government before the seed may be transferred to the commercial lay. The impact of mussel lays on the ecology, and in particular on the benthos, of the receiving area is largely unknown, which makes an accurate assessment of the potential impact of new lays impossible. The present study investigates the impact on the benthos of a mussel lay sited in an area in western inner Swansea Bay where mussels do not naturally occur.

The first commercial mussel lay in western inner Swansea Bay was established in September 1998, and since that time 3 further applications have been made for the establishment of more extensive lays in the immediate vicinity and extending over a large part of inner Swansea Bay. To date, one of these applications has been approved.

Swansea Bay is a high-energy embayment, located on the northern coastline of the Bristol Channel, with maximum depths of 20 m relative to chart datum (CD) and an extensive, low gradient intertidal zone (Fig. 1). The tidal current takes the form of a rectilinear, reversing offshore flow with an area of divergence on the eastern side of the embayment generating an anti-clockwise gyre in inner Swansea Bay (Collins et al. 1979). In inner Swansea Bay the sediments are mainly fine and medium sand with increasing proportions of mud occurring close inshore to the west, where Mumbles Head provides protection from wave exposure and the shallow water slows the tidal currents.

MATERIALS AND METHODS

Study site. The study site (51° 35.00' N, 03° 58.75' W) (Fig. 1) is situated in western inner Swansea Bay, at a depth of -0.7 m (relative to CD) within an area of substrate composed mainly of sand, which prior to the introduction of the mussel lay had remained unchanged for 2 yr (Smith 2002). The tidal currents are strong on the ebb tide and, although the area is largely protected by Mumbles Head from the prevailing southwesterly swell, it is exposed to short period wave action from the south and southeast.

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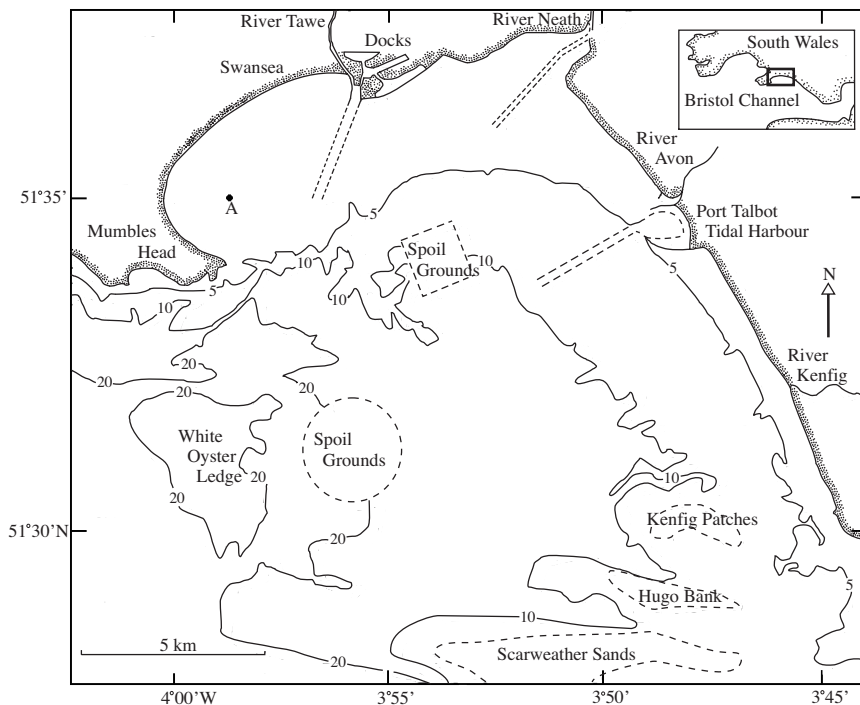


Fig. 1. Bathymetry of Swansea Bay (after Shackley & Collins 1984), showing the location of the sampling station (A). Depths of contour lines are given in metres

Sampling strategy. The site was sampled seasonally between January 1998 and December 1999 over high water Spring tides, using a 0.1 m² Day grab. Five replicate samples were taken from the site in accordance with the results of a pre-study 'power analysis' (Clark et al. 1997).

Treatment of samples. A sub-sample of sediment was taken from each of the 5 replicate samples at sea and the remaining sediment was sieved through a 1 mm mesh sieve. Sieve debris with retained fauna was preserved in 70% ethanol. Sediment samples were frozen on return to the laboratory and at a later date defrosted and analysed. Fauna were removed from the sieve debris by hand sorting, identified to species level whenever possible (using texts by Lincoln 1979, Hayward & Ryland 1995), counted (abundance) and their wet weights recorded (biomass). Epifauna were noted and identified although their abundance could not be quantified and they were not used in subsequent statistical analyses.

Each replicate sample of sediment was wet sieved through a 63 µm mesh to calculate the sand-to-mud ratio. The retained sand fraction was then oven dried at 50°C for 24 h, and the dried samples were mechanically graded through a sieve stack of sieve sizes of 1000, 500, 250, 125 and 63 µm.

The Difference-On-Ignition (D.O.I) method of Luczak et al. (1997) was used to determine the mean organic matter content of each set of 3 replicate sediment samples.

RESULTS

Sediment

Prior to the introduction of the mussel lay in September 1998, the study site had a predominantly sandy substrate (91 to 99% sand: 1 to 9% mud) (Fig. 2a,b). However, with the establishment of the lay and regular, commercial harvesting of mussels thereafter, abrupt changes in sediment composition soon became apparent at the site (Fig. 2a,b). This may be indicative of the habitat change brought about by the mussel culture and the effects of harvesting mussels by dredging. Mussels were laid in September 1998, and dredged in May and August 1999.

By August and October 1999, gross changes in sediment type were apparent with sand:mud ratios ranging from 4 to 81% sand:19 to 96% mud in August 1999 (shortly after mussel harvesting had occurred), and 15 to 96% sand:4 to 85% mud in October 1999

(the month of highest *Mytilus edulis* abundances; see Fig. 4a) (Fig. 2a,b). A parametric 2-sample *t*-test verified that there was a significant increase ($p < 0.05$) in mud content from August 1998 (no mussel lay) to August 1999 (post establishment of the lay). Consolidated clay deposits were also noted in the sediment samples of August 1999, which is possibly due to mussel harvesting by dredging, exposing underlying clay deposits.

Cumulative frequency curves for the sand fraction show that the sand was well sorted, composed of medium (26 to 62%) and fine sand (28 to 60%), which is typical of the sands being transported into the area. As expected, the sediment also became increasingly organically enriched as the mud content increased, with organic matter contents of 1 to 2% from January 1998 until a sudden significant increase ($p < 0.05$) occurred in August (8%) and October (5%) 1999 (Fig. 2c).

Fauna

Before the mussel lay was introduced, the benthic community at the study site was largely composed of polychaetes, gastropods, bivalves, amphipods and cirripeds, but was one in which polychaetes dominated (Table 1). Once the lay became established in Septem-

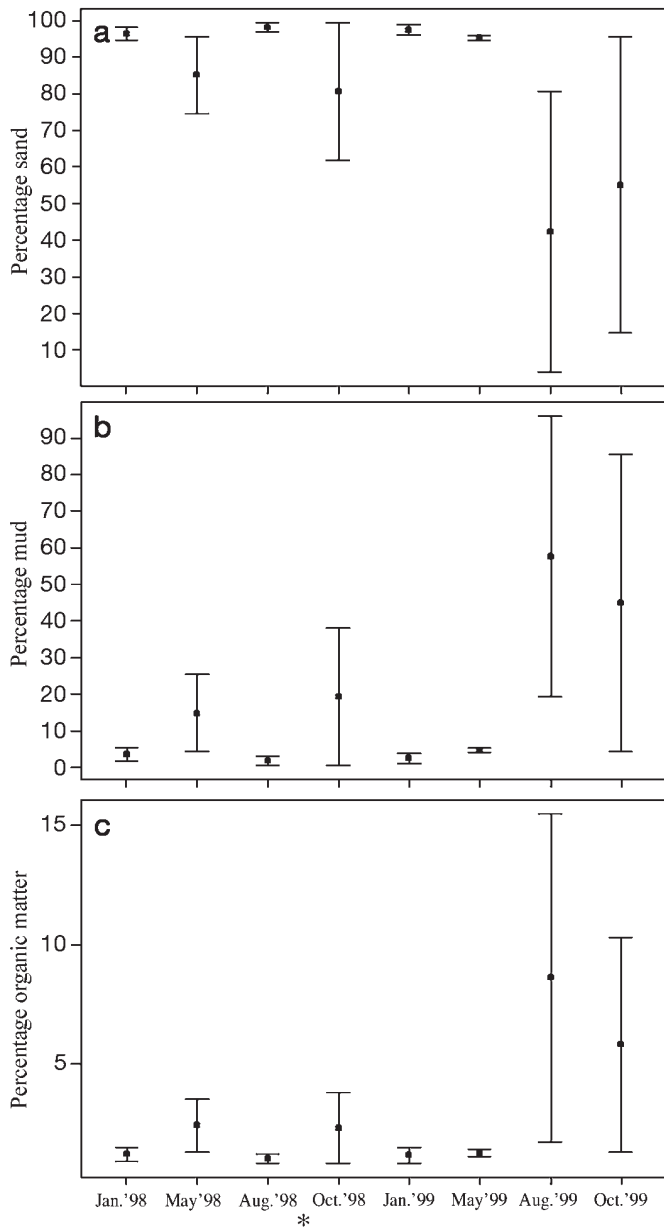


Fig. 2. Means and 95% confidence intervals of percentage of (a) sand, (b) mud, and (c) organic matter content of sediment obtained from the study site during 1998 and 1999. *September 1998 (mussel lay established)

ber 1998, there was a significant change in the species composition of the community. Polychaetes became less dominant as the relative proportion of bivalves, amphipods, decapods, ophiuroids and mysids increased (Table 1). A 2-sample *t*-test showed that there was a significant ($p < 0.05$) decrease in the number of species and an overall decline in the total number of individuals with the establishment of the lay.

The hierarchical agglomerative method (Fig. 3) shows the existence of 5 major groups (Groups 2, 3, 4,

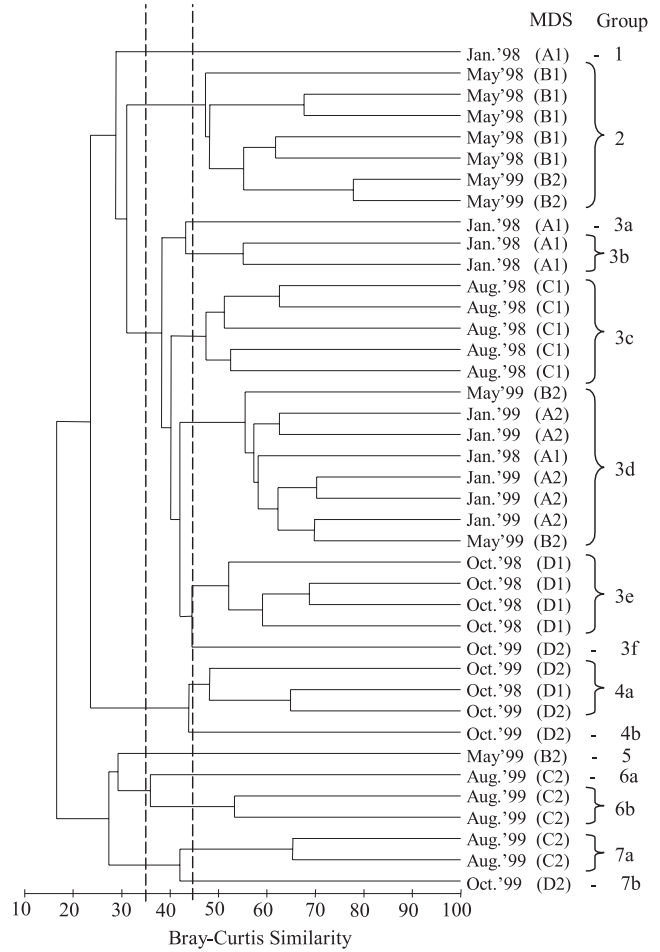


Fig. 3. Dendrogram for hierarchical clustering of the faunal abundances at the study site, using group-average clustering of Bray-Curtis similarities based on 4th root-transformed abundances

6 and 7) and 1 minor group (Group 1) of benthic species at the 35% similarity level, and the further division of Groups 3, 4, 6 and 7 into sub-groups at 45% similarity. Groups 2, 3a, 3b and 3c consist largely of samples obtained before the introduction of the mussel lay, whilst Groups 3d, 3e, 3f, 4, 6 and 7 are those samples taken after the establishment of the lay (Fig. 3). August and October 1999 are, again, the periods that are most separated from the other months sampled. Since August 1999 (Groups 6a, 6b and 7a) was a period in which there were no mussels (Fig. 4a) at the study site (as a result of mussel harvesting), separation from the other samples (Fig. 3) may reflect the effects of regular mussel harvesting on the benthic community. The separation of October 1999 from the other samples (Fig. 3) is possibly a result of this period having the highest abundances of *Mytilus edulis* (Fig. 4a).

The similarity percentage programme SIMPER (Clarke 1993) was used to investigate the contributions

Table 1. Percentage of individuals from the major taxa present at the study site

	Class Polychaeta	Class Bivalvia	Order Amphipoda	Order Decapoda	Class Gastropoda	Order Mysidacea	Class Ophiuroidea	Class Cirripedia	Phylum Pycnogonida
Jan '98	49.5	11.3	4.8	2.2	25.8	0.0	0.5	2.2	3.8
May '98	6.0	0.5	0.8	0.3	14.7	0.0	0.0	75.6	2.0
Aug '98	66.0	6.0	7.4	1.6	11.0	0.5	0.2	6.7	0.2
Oct '98	34.1	43.8	4.6	3.5	2.5	2.1	3.7	5.4	0.0
Jan '99	64.1	31.2	1.2	3.5	0.0	0.0	0.0	0.0	0.0
May '99	30.7	1.9	0.4	0.8	25.8	0.0	0.0	40.2	0.0
Aug '99	60.0	0.0	13.3	0.0	0.0	6.7	20.0	0.0	0.0
Oct '99	10.1	61.9	1.9	13.4	1.2	3.1	5.8	2.1	0.4

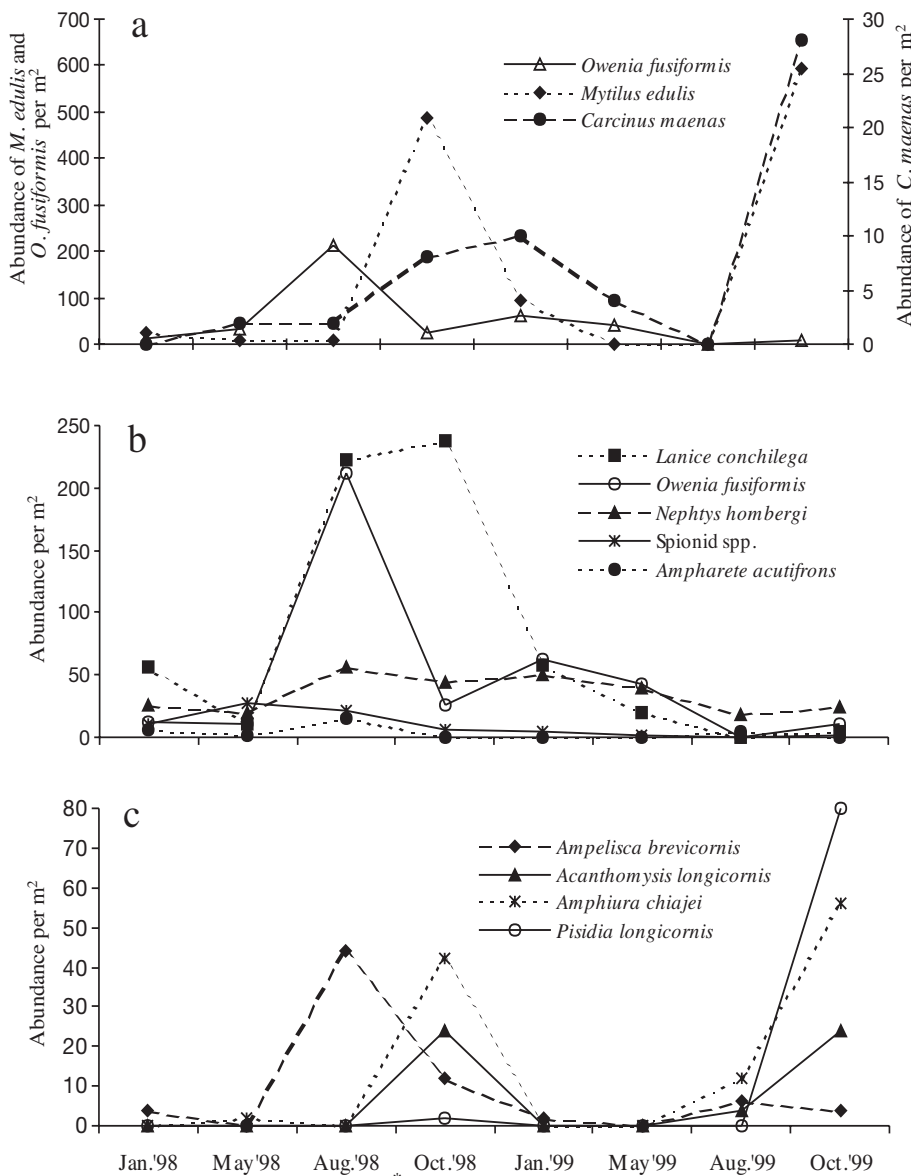


Fig. 4. Changes in the abundance of (a) *Owenia fusiformis*, *Mytilus edulis* and *Carcinus maenas*, (b) polychaetes and (c) crustaceans over the study period. *September 1998 (mussel lay established)

of individual species to the observed dissimilarities between the 1998 and 1999 samples of winter (January), spring (May), summer (August) and autumn (October). *Mytilus edulis* was the principal contributor (Table 2) to the dissimilarities between the winters of 1998 and 1999. The tube-dwelling polychaete *Owenia fusiformis* (Delle Chiaje) was also more abundant in January 1999 than in January 1998 (Table 2), but overall it was most prevalent in August 1998 (Fig. 4a).

In contrast, the slipper limpet, *Crepidula fornicata* (L.) (Table 2), the barnacle *Semibalanus balanoides* (L.) (occurring on the shells of *C. fornicata*) (Table 2), the polychaetes *Owenia fusiformis*, *Nephtys hombergi* (Savigny), *Ampharete acutifrons* (Grube) and spionid species (Fig. 4b), and the amphipod *Ampelisca brevicornis* (Costa) (Fig. 4c) were more abundant before the establishment of the mussel lay. The sand mason *Lanice conchilega* (Pallas) was abundant in August and October 1998, but decreased in abundance from this point onwards (Fig. 4b).

The shore crab *Carcinus maenas* (L.) occurred in relatively low abundance but increased in abundance between January 1998 and January 1999 (Table 2), and the greater increase between October 1998 and 1999 (Fig. 4a) indicates an association between the abundance of the shore crab and the mussel *Mytilus edulis*. There was an association between the shore crab and *M. edulis* (Spearman rank correlation $r_s = 0.725$) at $p = 0.1$.

The porcellanid crab *Pisidia longicornis* (L.), mysid *Acanthomysis longicornis* (Milne-Edwards) and brittle star *Amphiura chiajei* (Forbes) did not occur at the study site until after the mussel lay had been introduced (Fig. 4c). It is, therefore, possible that their peaks in abundance in October 1998 and 1999 (Fig. 4c) are related to the increased abundances of *Mytilus edulis* during these same periods (Fig. 4a).

Table 2. Top 10 ranked species responsible for the observed dissimilarities between samples of winter (January), spring (May), summer (August) and autumn (October) of 1998 and 1999 and their average abundances (m^{-2}) and individual contribution (%) to the average dissimilarity value

Species	Average abundance (1 m^2)		%	% average dissimilarity
	Jan 1998	Jan 1999		
<i>Mytilus edulis</i>	26	96	7.5	57.8
<i>Owenia fusiformis</i>	12	62	5.9	
<i>Crepidula fornicata</i>	96	0	4.5	
<i>Atylus swammerdami</i>	10	0	4.3	
<i>Carcinus maenas</i>	0	8	4.3	
Sabellid spp.	8	0	4.2	
Spionid spp.	10	4	4.2	
<i>Modiolula phaseolina</i>	10	0	3.4	
<i>Ampharete acutifrons</i>	6	0	3.2	
<i>Pagurus pubescens</i>	8	0	3.2	
	May 1998	May 1999		
<i>Semibalanus balanoides</i>	1024	212	11.2	65.5
<i>Crepidula fornicata</i>	196	136	9.5	
Spionid spp.	28	2	6.2	
<i>Phyllodoce groenlandica</i>	0	16	5.3	
<i>Eumida sanguinea</i>	0	14	4.6	
<i>Owenia fusiformis</i>	10	42	4.6	
Sabellid spp.	10	0	4.0	
<i>Lanice conchilega</i>	10	20	3.4	
<i>Nephtys hombergi</i>	20	40	3.3	
<i>Nymphon gracile</i>	18	0	3.2	
	Aug 1998	Aug 1999		
<i>Owenia fusiformis</i>	212	0	9.3	85.3
<i>Lanice conchilega</i>	222	0	9.2	
<i>Crepidula fornicata</i>	94	0	6.2	
Spionid spp.	22	0	5.5	
<i>Ampelisca brevicornis</i>	44	6	4.1	
<i>Spisula subtruncata</i>	14	0	3.8	
<i>Eumida sanguinea</i>	12	0	3.7	
<i>Mytilus edulis</i>	12	0	3.4	
<i>Semibalanus balanoides</i>	58	0	3.3	
<i>Ampharete acutifrons</i>	16	4	3.1	
	Oct 1998	Oct 1999		
<i>Lanice conchilega</i>	238	4	9.5	59.8
<i>Mytilus edulis</i>	486	592	6.2	
<i>Eumida sanguinea</i>	22	0	4.7	
<i>Acanthomysis longicornis</i>	24	24	3.6	
<i>Abludomelita obtusata</i>	28	0	3.5	
Aphroditid spp.	24	10	3.5	
<i>Pisidia longicornis</i>	22	96	3.4	
<i>Amphiura chiajei</i>	42	56	3.3	
<i>Owenia fusiformis</i>	26	10	3.3	
Cirratulid spp.	8	20	3.3	

Trophic relationships

As a consequence of the filter-feeder *Mytilus edulis* becoming the dominant organism (in terms of biomass) through the introduction of the lay, other benthic filter-feeders were out-competed and there was an overall decline in species which can both filter-feed and surface deposit-feed (*Lanice conchilega* and *Owenia fusiformis*), whilst the abundance of deposit-feeders and carnivores increased (Fig. 5). It appears, however, that during those periods when there were no mussels (i.e. May & August 1999) (Fig. 4a), as a result of mussel harvesting, the filter-feeders *Crepidula fornicata* and *Semibalanus balanoides* (occurring on the shells of *C. fornicata*) regained their dominance in May 1999 (Table 2), whilst the carnivorous *Nephtys hombergi* (Fig. 4b), and the deposit-feeders *Amphiura chiajei* and *Ampelisca brevicornis* dominated in August 1999 (Fig. 4c).

It is also possible that the tube-dwelling polychaetes, i.e. the filter-feeder/surface deposit feeders *Lanice conchilega* and *Owenia fusiformis* (Fish & Fish 1996) (Fig. 4a,b) and the deposit-feeder *Ampharete acutifrons* (Martin et al. 2000) (Fig. 4b), were physically smothered by the mussel lay. The decline in the deposit feeding amphipod *Ampelisca brevicornis* (Nybakken 1993) (Fig. 4c) may be due to predation by increased numbers of carnivorous shore crabs *Carcinus maenas* (Fig. 4a) that appear to have resulted from the establishment of the mussel lay, or this species may have simply been unable to adapt to the change in habitat. The apparent occurrence of the deposit feeding brittle star *Amphiura chiajei* and the filter-feeding porcellanid crab *Pisidia longicornis* (Fish & Fish 1996) with the establishment of the mussel lay (Fig. 4c) is possibly due to the lay providing both species with suitable substrates. That is, *A. chiajei* with a muddy environment and *P. longicornis* with a secondary hard bottom (Hayward & Ryland 1995). During those periods, however, when mussels were harvested (i.e. May & August 1999) (Fig. 4a), an overall decline was noted in both species (Fig. 4c).

DISCUSSION

Within a year of commencement of the mussel fishery in western inner Swansea Bay, there was a significant change in the species

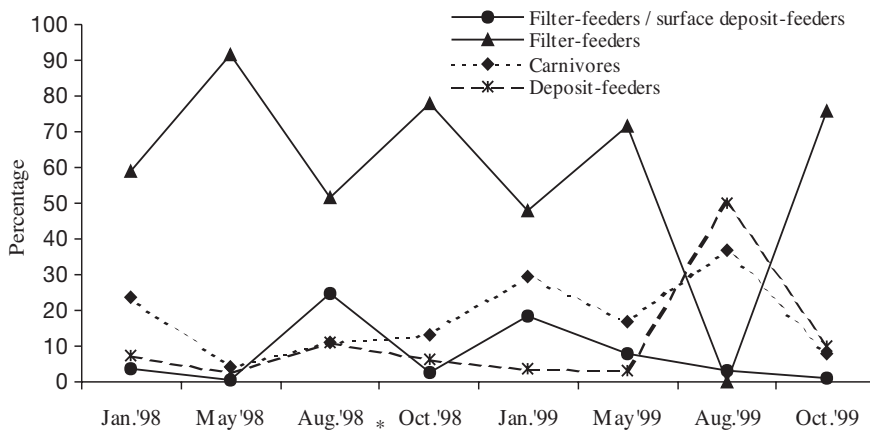


Fig. 5. Changes in the occurrence of different trophic groups at the study site.
*September 1998 (mussel lay established)

composition of the benthic community at the study site, with a decrease in the number of species and in the total number of individuals. These changes may be attributable to the habitat change brought about by the mussel culture, and regular, commercial mussel harvesting preventing the age and size of the mussel patches increasing above a certain point, which would have limited the diversity of the associated invertebrates (Tsuchiya & Nishihira 1985, 1986, Caldow et al. 2003).

It is possible that the tube-dwelling polychaetes *Lanice conchilega*, *Owenia fusiformis*, *Ampharete acutifrons* and those spionid species inhabiting sandy tubes were physically smothered when the lay was initially developed. However, through the creation of a structurally complex habitat, it appears that the mussel lay modified the physical environment which, in turn, shaped the associated community by providing microhabitats (e.g. for juvenile crabs; Moksnes et al. 1998, Moksnes 2002) and an organically enriched environment (Beadman et al. 2002, Saier 2002, Thiel & Ullrich 2002). Mussel shells provided a hard substrate for sessile epibionts (Asmus & Asmus 2002), whilst the mussels provided a supply of fine sediments (faeces and pseudofaeces), i.e. a food resource for many species, both within and underneath the mussel matrix (Tsuchiya 1980, Kröncke 1996, Ragnarsson & Raffaelli 1999).

Mussels are extremely efficient filter-feeders (Kautsky & Evans 1987, Granby & Spliid 1995), and in the densities found at the study site, they would have out-competed other filter-feeders for seston and phytoplankton (Obert & Michaelis 1991, Beadman et al. 2002) and would have effectively prevented or reduced the settlement of these organisms by ingestion of their larvae (Cowden et al. 1984, Morgan 1992). Thus, the filter-feeding slipper limpet *Crepidula fornicata* was probably out-competed by *Mytilus edulis*, but was

able to regain dominance periodically when *M. edulis* was harvested.

Increased abundances of epibenthic crustaceans (*Carcinus maenas*, *Acanthomysis longicornis* and *Pisidia longicornis*) and deposit-feeders (*Amphiura chiajei*) agrees with past studies (Comito 1987, Ragnarsson & Raffaelli 1999, Thiel & Ullrich 2002), which found that mussel beds bring about the recruitment of epibenthic crustaceans, whilst biodeposition provides a food source for benthic deposit-feeders. Given that shore crabs *C. maenas* prey on *Mytilus edulis*, polychaetes and crustaceans (Dankers & Zuidema 1995, Moksnes 2002), increased numbers of crabs may, therefore, have been responsible for the decline of the

amphipod *Ampelisca brevicornis* and the polychaete *Nephtys hombergi*.

Furthermore, since modest reductions in mussel density increase turbulence (as a result of greater bed roughness), which enhances sediment erosion and resuspends biodeposits (Dolmer & Frandsen 2002, Widdows et al. 2002), it is possible that mussel harvesting (by dredging) would have made the lay more vulnerable to erosion by tidal currents and storms, changed the topography and composition of the seabed, and resuspended sediment and nutrients (Dolmer & Frandsen 2002).

CONCLUSIONS

From the present study, it can be concluded that mussel lays are biotic structures that can affect the ambient ecosystem (Asmus & Asmus 2002). Given that inner Swansea Bay is an important nursery ground for juvenile flatfish (Mignot 1996), dependent on the benthos as a source of food (Beyst et al. 1999, Amara et al. 2001), a change in the availability and distribution of food organisms could change their feeding behaviour, which could affect growth patterns and recruitment. Further expansion of the mussel fishery may also reduce food sources for other filter-feeding organisms. It is important, therefore, that the carrying capacity for mussel cultivation in Swansea Bay should be investigated in order to minimize the impact of mussel lays on the ambient ecosystem.

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