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A Literature review on particle assimilation by molluscs and crustaceans

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Literature review on particle assimilation by molluscs and crustaceans

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Summary

Literature on the size of particles ingested by bivalves and crustaceans was examined. In bivalves, particles above a minimum size (from 1 to 7μm diameter) were preferentially ingested, and particles above around 50μm were rejected because they did not fit in the groove in the Ctenidium. Inorganic particles of any size were less likely to be accepted than digestible particles. However, examination of gut contents revealed that much larger particles than this, up to the order of 400μm, were sometimes ingested and could remain in the gut for much longer than food items, so that the risk of contamination associated with eating these particles would seem to be higher than their low rate of ingestion would indicate. Bivalves became much less selective when suspended particle concentrations were low. The prevalence of these large particles in the gut appears to be greatest in oysters, but this may be a bias in the studies, since large particles were also found in cockles.

There is much less information on particle selection by decapods. Many small decapod species and larvae apparently consumed large food items, but these were organic, in effect prey items, so the maximum size of inorganic particle that may be ingested is uncertain. Given the prevalence of bivalve species in the prey of many decapods, the limit size of particles ingested by bivalves would constitute a lower estimate for this. Filter feeding gastropods preferentially consume particles up to around 60μm, although there is limited evidence of larger particles being ingested.

Contents

1. Introduction

A literature review was carried out for studies of ingestion in commonly eaten invertebrate species. The groups of species are listed below. The search was carried out using Scopus (www.scopus.com) using terms related to the taxons under study – e.g. bivalves, gastropods, decapods – and lower level classifications within these under 'titles/keywords/abstracts'. Terms searched alongside included 'particles', which returned few results, 'contaminants' and 'feeding/ingestion', which yielded a large number of results (around 2000) that could be checked by title and abstract. The primary articles were checked for references and citations within Scopus. The database search goes back to 1960 although there were few records in the primary search due to lack of abstracts and keywords for searching. Specific species-only searches were carried out for important species such as *Cancer pagurus* (edible crab) (200 records but only four of relevance). Scopus also gave references on the world wide web, but since most of these were educational or concerned with aquarium management only a cursory examination was made of these. The search revealed about 200 articles worth further examination.

Both molluscs and crustaceans are consumed by humans and are obligate or facultative filter feeders. There exists a body of knowledge on uptake of soluble inorganic pollutants (such as arsenic and mercury from methyl-mercury) e.g. Fisher et al. (1996). However the main understanding about uptake of particulate contaminants comes from studies primarily undertaken to study feeding behaviour.

The main classes of molluscs and crustaceans consumed by humans are:

Bivalves (mussels, cockles, oysters, clams) – obligate filter feeders.

Cephalopods (octopus, squid, cuttlefish) – these are predators and there is no information on the size of incidentally captured particles. In any case, gut is unlikely to be consumed.

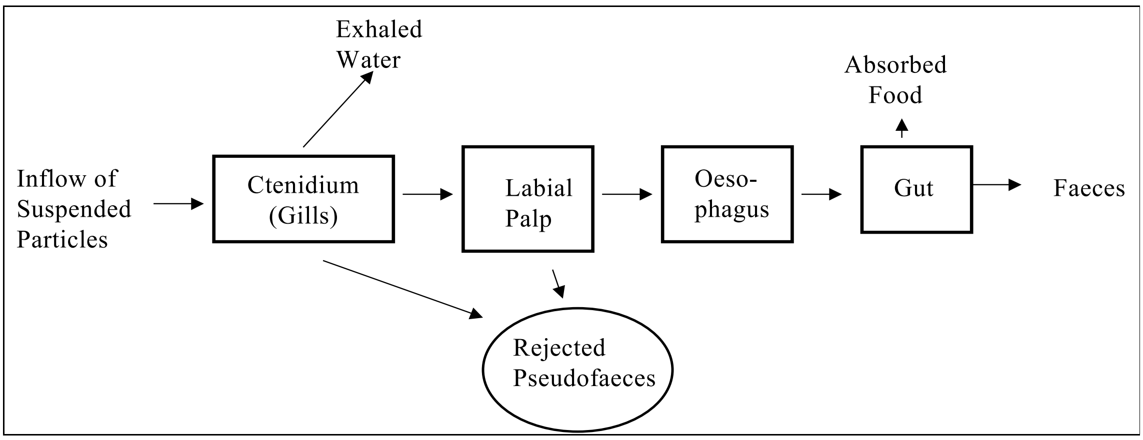
Gastropods (whelks, periwinkles) – mixture of feeding modes, with some filter feeding.

Crustaceans of the order **Decapoda** (crab, lobster, *Nephrops*) – most of which engage in filter or scavenging behaviour, though many crabs and lobsters are primarily predators.

2. Bivalves

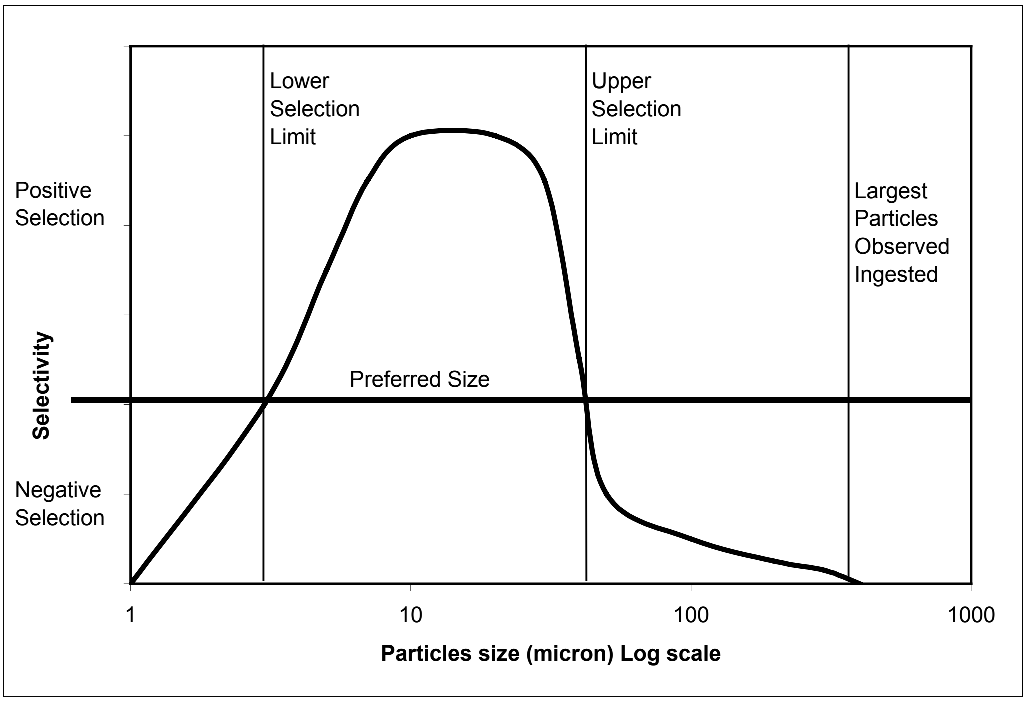
The feeding mechanism of bivalves is a process of active sorting whereby particles of different sizes are ingested. This process is an active one (so that bivalves are not simply passive filter feeders) with nutritious organic prey ingested and non-edible particles rejected (Owen 1974) (see *Figure 1*). Particles of sufficient size (typically between 1μm and 7μm depending on species, (Sobral & Widdows, 2000; Winter, 1978; Mølenberg & Riisgård, 1978; Haven & Morales-Alamo, 1970)) are removed from the water by filtration and then sorted by the palps on the labia into ingested particles and non-ingested particles which are encased in mucus and then rejected from the mouthparts as pseudofaeces (Jørgensen, 1975; Levinton et al. 1996). The lower selection limit (*Figure 2*) was highest for *Pecten* (scallops) species and smallest for *Cardium* (cockles) (Hawkins et al. 1998, Beninger et al. 1999). However, this sorting is not precise and will be affected by factors such as particle concentration. Furthermore in many cases there was little sorting between different kinds of organic matter (Shumway et al. 1985), and there is some debate as to the extent to which sorting is sufficiently controlled to optimise the intake of required nutrients (Bayne 1998). Jørgensen (1996) specifically rejected sorting by food value, whilst acknowledging sorting by size, shape and other physical attributes. Nevertheless it was observed that concentration of inorganic contaminants were higher in the pseudofaeces than in the suspended particulate matter on which they fed (Allison et al. 1998).

Figure 1: *Simplified model of filter food processing by bivalves.*



Mussels, mainly *Mytilus edulis,* are generally considered to be herbivorous filter feeders with phytoplankton and bacteria the main part of their diet, although zooplankton may be consumed as well (Davenport et al. 2000; Rouillon & Navarro, 2003). Field (1911, see Newell et al. 1989) observed a wide range of items in the gut of *M. edulis*, particularly diatoms and dinoflagellates. These could be 200 μm or more in length, though were typically elongate so usually no more than 40 μm in diameter. A similar maximum diameter for typical ingested particles was reported in Oysters (*Crassostrea gigas*) by Dupuy et al. (1999). There would seem, however, to be a tendency for larger inorganic (SiO_2) particles to be rejected with Defossez & Hawkins (1997) reporting particles of 18.7μm and above were increased in relative concentration in the surrounding water – i.e. they were not taken up. Lehane & Davenport (2002) reported a wide range of animal parts inside the guts of mussels and oysters, indicating a degree of carnivory in species commonly assumed to be herbivorous. Widdows et al. (1979) reported that the size of food items ingested by *M. edulis* was typically less than 40μm, with the largest sized, around 30μm, being taken up in spring and summer.

Figure 2: *General pattern of size selectivity by bivalves, showing positive selection for particles above a lower limit of a few microns, which peaks for mid-sized particles, typically 20-30μm, and then falls off above 40μm, but with a few large particles nevertheless being ingested. The absolute magnitude of selection depends on concentration, species and type of particle.*



For bivalves feeding from suspended particles when particle organic matter was low and particle concentration was low, the feeding efficiency effectively becomes negative (the energetic costs of feeding, including selection, exceed the nutritional benefits of the food ingested) (Velasco & Navarro 2002). In these conditions bivalves tend to reduce their active sorting of particles (Deslous-Paoli et al. 1992, Raillard et al. 1993). For *Mytilus edulis* this threshold is about 5mg l^{-1} (Widdows et al. 1979). This only refers to Seston (particles suspended in fluid) feeders, so that bottom feeders will to some extent always be selective.

Cockles (*Cerastoderma edule)* were shown to ingest particles in the range 2 – 12 μm with preference for the larger particles – there were, however, no particles above 12μm in the sediment (Iglesias et al. 1992). On the other hand, Karlsson et al. (2003) observed uptake of large organic particles (cellulose) of 60 to 500μm. This was under controlled conditions when the availability of such large particles had been artificially increased, although the same authors also noted sand grains of up to 600μm in the cockles' intestines.

Scallops (*Placopecten magellanicus*) were capable of extracting particles up to 40 μm from a variety of sediment and debris types (Cranford & Grant, 1990). It was noted that size selectivity was highly variable between individuals, with selection for or against larger organic particles of sizes up to 72 μm (MacDonald & Ward, 1994). However, the majority of particles in this study were in the range 2 – 12 μm.

Scallops also showed a difference in the post-ingestive processing of inorganic versus organic components with inorganic (polystyrene beads coated with ^{51}Cr) being retained longer in the stomach (Brilliant & MacDonald 2002), potentially leading to an increased duration of time for which the shellfish remain contaminated after ingestion of radioactive particles. The retention time of larger organic particles is also longer (Brilliant & MacDonald 2000).

The clearance rate of particles by scallops has been shown to be dependent on the organic matter concentration as well as the size of the inorganic particles – clearance rates reach their theoretical maximum at around 20μm or above for inorganic particle size, suggesting a reduced uptake of particles above this size in scallops (Brilliant & MacDonald 2000). Similarly, Stenton-Dozey & Brown (1992) reported that clams (*Venerupis corrugatus*) cleared particle sizes of between 8 – 13 μm most efficiently, but this was from a pool where the maximum recorded particle size was 23μm, so no large particles were present.

Clams of the genus *Potamocorbula* would ingest polystyrene particles of 44μm (Penry 2000), providing their concentration was sufficiently low to avoid rejection. It was hypothesised that inert particles of this size would pass from stomach to intestine and not into the digestive gland. If it were to do so, it would be liable to become stuck impeding further digestion of other particles.

The clams seemed capable of passing these particles and it was not known how often such a large particle could become stuck in the body, although there was evidence that this happened. Polystyrene beads of 20 μm were found in the digestive glands of scallops (*Placopecten magellanicus*) following feeding. Ingestion of plastic spheres seemed to be reduced at the point of faeces production in zebra mussels, indicative that they were learning to differentiate indigestible material (Lei et al. 1996)

Observations on stomach contents of larvae of three bivalve species – mussels, scallops and clams (Raby et al. 1997) again indicated food items in the range <5 up to 25 μm, together with a few >25 μm up to 40μm in diameter. The largest size classes taken were dominated by dinoflagellates, and the uptake of these larger food items was greater for mussels than for clams when the bivalve larvae were large, and equal for smaller larvae.

Tamburri & Zimmer-Faust (1996) reported the ingestion of inert particles by Oysters (*Crassostrea virginica*). Particles up to 400μm were ingested, and there was no significant difference between light (polystyrene) and heavy (glass) particles – but ingestion percentage declined with particle size, with only 20% of 275μm particles ingested. Examination of gut contents also showed large particles of up to 300 μm were found in oyster stomachs and may have had a role in food grinding (Bernard 1974).

Cognie et al. (2003) also reported the acceptance of large food items of over 150μm in all dimensions, despite being larger than the 75μm of the principal filament – the selection site was therefore assumed to be the labial pulps. Baldwin & Newell (1995) reported that oyster (*Crassostrea virginica*) larvae commonly consumed prey up to 12μm in diameter but could extend this to particles of up to 30μm in certain conditions where large food items were predominant. Barille et al. (1997) reported that 95% of particles ingested by *Crassostrea gigas* were in the range 2 – 20 μm, although this result reflected the distribution of particles sizes in the seston. The preferred food size of Chilean oysters (*Ostrea chilensis*) was from 20μm to 75μm, typical of the size of their microplankton prey (Dunphy et al. 2006). In oyster larvae, by contrast, particle sizes <10 μm were preferred (Fritz et al. 1984, Wilson 1980), although Mackie (1968) found older oyster larvae selected food items of up to 30μm diameter.

It can be concluded that the main constraints on the size of ingested particle sizes in bivalves are behavioural – the active seeking out of suitable food, rather than physical – larger particles of 50μm and above can be ingested and processed. The size of particles ingested by Oysters is generally the largest recorded, with sizes of up to 400μm, although there is limited evidence of larger particles being ingested by cockles (up to 600μm). Large inorganic particles of around 40 – 50 μm are ingested when the concentration of organic matter is low to avoid the costs of active particle filtration.

It should also be noted that the conclusions of size ingestion in many studies are limited by the material with which the bivalves were presented. For example, in a survey conducted by Ward & Shumway (2004) of 43 studies of preingestive selection, only three used particles that exceeded 40μm.

3. Decapods

There is generally less information about decapod crustaceans. In addition many decapod species are primarily predators so that particle ingestion may be incidental to feeding behaviour and consequently not explicitly studied. The most commercially significant species are primarily consumers of bivalves (Lake et al. 1987, Mascaró & Seed 2001). Larvae of the larger decapods tend to be filter feeders and so some studies have been carried out on these.

Hinz et al. (2001) noted that plastic beads tended not to be ingested by crab larvae, unless they were associated with *Prorocentrum micans* (ratio 1 part in 20 *Prorocentrum*) – otherwise around 5% of the beads presented were taken up. Shaber & Sulkin (2007) also noted the tendency for larval crabs to take up dinoflagellates of approximately 40μm in size.

The antennal collectors of small suspension feeding crabs (*Emerita talpoida*) were able to pick up particles of 25μm (Canova, 1999) but this study gave no indication of likelihood of acceptance of inert particles.

Larval crabs of *Hemigrapus oregonensis* survived only with prey of larger sizes (*Prorocentrum micans* 75μm and *Artemisia* 300μm and above) (Lehto et al. 1998). These results were indicative of a carnivorous diet although smaller particles, such as algae of size approximately 10μm were taken along with detritus. These experiments did not really reveal the selectivity of the crab larvae to larger inorganic components. Tropical mud crab larvae readily took up microbial bound particles of up to 400μm in the largest larval stages (Genodepa et al. 2004), but this species is unlikely to be found in UK waters.

Sand Crabs, *Emerita analoga*, showed a small increase in ingestion rate when presented with a supply of 62μm glass beads; they also accepted food items, *Artemia,* of 150 μm (Efford, 1971).

Examination of the presence of plutonium in *Cancer pagurus* indicated that radioactive contaminants passed across the gills but were not taken up into the edible parts of the crab (Guary et al. 1976).

Shrimps of the order Thalassinidae (Pinn et al. 1998), potential prey for larger decapods, were shown to select against particles larger than about 10μm in two species of genus Upogebia, but there was no significant selection in three other species, indicating that particles of more than 50μm could be ingested. On the other hand Stamhuis et al. (1998) suggest that 30μm is potentially the largest size of particle capable of being trapped by the maxillipeds. Hunt (1992) suggests that larger particles than this are directly pushed in by the mouthparts. Ghost shrimps *Biffarius arenosus* and *Tryaea australiensis* tended to reject particles > 63 μm in diameter with *B. arenosus* preferring particles <15.6 μm (Stapleton et al. 2002). Brine shrimps (*Artemia*) had a preferred particle size of around 16μm and did not ingest particles larger than 50μm (Fernández, 2001). Examination of ingestability and weight gain of particle feeds in shrimps (Obaldo et al. 1998) revealed that they had difficulty in ingesting particles sizes above 124μm.

4. Gastropods

A number of gastropod species are deposit feeding (Kamimura & Tsuchiya, 2004), primarily consuming various microbes such as microalgae and a questionable amount of detritus (Levinton et al. 1984). Mud snails (*Hydrobia totteni*) showed a preference for particles between 41 and 63 μm (Levinton & DeWitt, 1989), including glass beads, but larger particles over 100μm were taken. There was considerable variation in particle choice depending on particles available in the substrate. Whitlatch & Obrebski (1980) reported that deposit-feeding gastropods fed on diatoms ranging in size up to 36μm, with preferred size varying with the size of the predator.

5. Conclusions

Particle acceptance and rejection is a process of active sorting not passive filtration. It has been observed that even within the species of organic matter, there will be selection for a preferred food over a less favoured one and that this has something to do with taste or nutritive value more than size (although size is an issue). Because of this taste effect it is not straightforward to evaluate the risk of novel particle ingestion, although the most reasonable assumption is that radioactive particles are similar to other dense inorganic particles, for example silicates, with regard to their uptake.

Overall, there is evidence of preferential uptake in mollusc species of particles of ~50μm, but inorganic particles of this size are not taken up often. However, the general observation from a variety of bivalve and gastropod species is that larger particles, organic and inorganic, are occasionally taken up, even though they are not actively selected. Bivalves and gastropods seem to be capable of ingesting particles in excess of 100μm. There is strong evidence for uptake of such large particles in oysters, but even mussels and cockles have been observed to contain large particles, up to a maximum of 600μm. Furthermore these larger particles may be less readily excreted than particles in the size range of normal food.

Other common invertebrate species – *Nephrops norvegicus, Cancer pagurus* and Cephalopod species are primarily carnivorous. Typical prey sizes for crab larvae are variable, but are typically up to 300μm. For adults prey items may be large and include bivalves and crustaceans. The substantive question is the extent to which there may be incidental uptake of inorganic particles.

In conclusion, particle sizes up to 50μm are liable to be consumed by commonly eaten mollusc species. However this consumption will not be preferential and so the risk will be lower (by a factor of 5-10) than the probability indicated by comparing numbers of contaminant particles than food particles in this size range. There is also a risk of ingestion of larger particles in the range 300 – 600 μm. This risk is impossible to assess from ingestion studies as ingestion of particles in this range is rare and seldom studied. However, examination of gut contents reveals that this does happen, especially in Oysters (but also observed in cockles and probably in other species). The risk of these particles is that they may be retained for a long time – and may be beneficial to the organisms by aiding digestion. No evidence was found of particles above 600μm in diameter being ingested.

For crustaceans the position is less clear, although the figures given for bivalves would serve as a first estimate. Although many crustaceans, particularly crab species, do take larger food items, it would seem that this is in response to specific prey – which would have had to ingest a contaminated particle first of all.

There is a deficiency of data for many species, especially decapods and gastropods. Gastropods, in particular, may be a significant component of local diet even though they are not major food items for the UK population as a whole. Furthermore there is little information on the risks associated with secondary consumption by commonly eaten predator species such as edible crabs (*Cancer pagurus*) that would indicate the largest inorganic particle sizes that may be consumed by such species. Furthermore the risk from consumption of such species would be moderated by the likelihood of human consumption of the parts of the animal most likely to contain contaminants, especially the gut. Even for those species where the pattern of contamination and retention is clearer, notably the various bivalve species studied, there must be caution in interpretation in that most of the studies have been directed at typical consumption for food intake studies and not at abnormal particle intake. There is a need, therefore, to carry out experimental studies on the kinds of particles absorbed using experimental designs similar to those referred to in this report, but incorporating metallic particles of a range of sizes. The studies could be extended by looking at the long-term absorption of metallic particles (which would not need to be radioactive) in an aquarium system designed to be as natural as possible.

In the absence of specific experimental evidence on the uptake of large particles in different species we would make a general recommendation that the possibility of ingestion of particles of sizes up to 1mm should be taken into account in risk assessment (that is allowing a safety margin above the 600μm, which is the largest size recorded). This would seem to apply to all species of bivalves, which recorded similar maximum particle sizes, even though the size of preferred particles varies. For other species, there is no evidence of general intake of larger particle sizes although the degree of uncertainty is higher, so that the 1mm rule would seem to be an appropriate one.

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