

A review of the infectious agents, parasites, pathogens and commensals of European cockles (*Cerastoderma edule* and *C. glaucum*)

MATT LONGSHAW¹ AND SHELAGH K. MALHAM²

¹Cefas Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset, DT4 8UB, ²Bangor University, School of Ocean Sciences, Centre for Applied Marine Sciences, Menai Bridge, Anglesey, LL59 5AB

A systematic review of the parasites, pathogens and commensals of the edible cockle (Cerastoderma edule) and of the lagoon cockle (Cerastoderma glaucum) has been completed. A total of 59 different conditions have been reported throughout the range of both of these hosts; of these 50 have been reported in edible cockles, and 28 in lagoon cockles. Cockles are hosts to viruses, bacteria, fungi (including Microsporidia), Apicomplexa, Amoeba, Ciliophora, Perkinsozoa, Haplosporidia, Cercozoa, Turbellaria, Digenea, Cestoda, Nematoda, Crustacea and Nemertea. A number of these have been reported sporadically although they may be associated with mortalities. In particular, mortalities have been associated predominately with digeneans and some protistan infections. In many cases pathology is marked in affected animals and parasites have been shown to reduce fecundity, alter burrowing behaviour and limit growth. This review provides information on the individual and population effects of these conditions as well as providing suggestions for future research. In particular, there has been a lack of taxonomic rigour applied to many studies and as a result there are a number of erroneous host records. There is a need to re-describe a number of parasite species and to determine the life cycle of those considered to be important mortality drivers.

Keywords: parasite, disease, commensals, cockles, distribution, taxonomy, pathology

Submitted 23 March 2012; accepted 25 May 2012; first published online 30 August 2012

INTRODUCTION

Cockles are a small bivalve occurring intertidally and subtidally around the coastline of Europe. Under normal conditions they remain buried in the sediment and feed via a siphon. *Cerastoderma glaucum* (Bruguère, 1789), the lagoon cockle, tends to occur in non-tidal areas such as lagoons and salt marshes whilst *C. edule* (L. 1758), the edible cockle, is more likely to be found on open coasts and estuaries (Reise, 2003). They occur from Norway to Morocco and through the Baltic, Mediterranean and Black Sea. Mortalities of cockles and catastrophic declines in cockle populations have been reported for many years with predation, disease, climatic events, pollution, failed recruitment and over-fishing being suggested as important factors (Ducrotoy *et al.*, 1989). Furthermore, it is recognized that cockles are hosts to a wide variety of parasites and diseases. Many of these are normally relatively innocuous but can become problematic particularly if prevailing environmental conditions are poor and have been implicated in mass mortality events leading to declines in cockle populations. Mortalities of cockles were reported in the Burry Inlet (Loughor Estuary, Wales) in the 1950s and 1960s, which were attributed to environmental conditions and predation by man and oystercatchers (Hancock, 1970). However, whilst Hancock (1970) acknowledged that there were a number of parasites in cockles from the Burry

Inlet that had been previously implicated in mass mortalities, that study only considered that they might have been problematic during ‘times of stress, such as cold winters and hot summers’. Lauckner (1984) in examining cockles from the German North Sea coast concluded that digeneans were an extremely important component of the biota and, in agreement with Hancock & Urquhart (1965) thought infected cockles were likely to be less resistant to thermal stress as a result of infections with Digenea. To date almost 60 parasites and disease conditions have been described or reported from *C. edule* and *C. glaucum* (see Table 1). A schematic of the life cycles of most of the cockle parasites is shown in Figure 1. This systematic review covers all the groups of pathogens reported for both the lagoon cockle and the edible cockle throughout its range (Table 2).

VIRUSES AND VIRUS-LIKE PARTICLES

Disseminated neoplasias, also called haematopoietic, haemic, haemocytic neoplasia or disseminated sarcoma (Figure 2A) have been widely reported in *Cerastoderma edule* and to a lesser extent *C. glaucum* in Ireland, Spain and France (Poder & Auffret, 1986; Twomey & Mulcahy, 1988; Carballal *et al.*, 2001; Le Grand *et al.*, 2010). Spatio-temporal variations in prevalence have been reported and mortalities associated with the condition are known to occur (Twomey & Mulcahy, 1988; Carballal *et al.*, 2001; Villalba *et al.*, 2001; Ordás & Figueras, 2005; Le Grand *et al.*, 2010). Prevalence

Corresponding author:

M. Longshaw

Email: matt.longshaw@cefas.co.uk

Table 1. Digenea reported from cockles (*Cerastoderma edule* and *C. glaucum*) along with details of the organs affected, other hosts directly involved in the life cycle and appropriate references.

Species	Synonyms	Organs affected	1 st Intermediate host	2 nd intermediate host	Final Host
<i>Himasthla continua</i>	–	Foot	<i>Hydrobia ulvae</i>	<i>Cerastoderma edule</i> , <i>Cerastoderma glaucum</i>	<i>Larus</i> spp.
<i>Himasthla elongata</i>	<i>Himasthla secunda</i> <i>Echinostomum secundum</i>	Foot	<i>Littorina littorea</i>	<i>C. glaucum</i> , <i>C. edule</i>	<i>Larus</i> spp., <i>Haematopus ostralegus</i> , <i>Somateria mollissima</i>
<i>Himasthla interrupta</i>	–	Mantle, foot	<i>H. ulvae</i>	<i>C. edule</i> , <i>C. glaucum</i>	<i>Larus</i> spp.
<i>Himasthla quissetensis</i>	–	Foot, sometimes mantle margins	<i>Cyclope neritea</i> , <i>Nassarius reticulatus</i> , <i>Ilyanassa obsoleta</i>	<i>C. glaucum</i> , <i>C. edule</i>	<i>Larus</i> spp.
<i>Curtuteria arguinae</i>	–	Mantle and foot	Gastropod?	<i>C. edule</i>	Birds?
<i>Renicola roscovita</i>	–	Palps	<i>L. littorea</i>	<i>C. edule</i> , <i>C. glaucum</i>	Birds
<i>Psilostomum brevicolle</i>	<i>Psilostomum platyurum</i>	Visceral mass	<i>H. ulvae</i>	<i>C. edule</i> , <i>C. glaucum</i>	<i>H. ostralegus</i> , <i>Larus</i> spp.
<i>Gymnophallus choledochus</i>	<i>Cercaria dichotoma</i> , <i>Cercaria fulbrighti</i> , <i>Cercaria hueti</i>	Gonad, digestive gland	<i>C. edule</i> , <i>C. glaucum</i>	<i>C. edule</i> , <i>Nereis diversicolor</i> , <i>Diopatra neapolitana</i> ,	Birds
<i>Gymnophallus fossarum</i>	<i>Meiogymnophallus fossarum</i> ; <i>M. minutus</i> in part	Peripheric extrapallial space, in the folds of the mantle margins	<i>Scrobicularia plana</i>	<i>C. glaucum</i> , <i>C. edule</i>	<i>H. ostralegus</i> , <i>Larus</i> spp.
<i>Gymnophallus gibberosus</i>	–	Anterior adductor muscle	<i>Macoma balthica</i>	<i>C. edule</i> , <i>C. glaucum</i>	Birds
<i>Gymnophallus minutus</i>	<i>Meiogymnophallus minutus</i> , <i>Gymnophallus oidemiae</i> , <i>Distomum minutum</i> , <i>Gymnophallus oedemia</i> , <i>Cercaria margaritae</i> , <i>Cercaria cambrensis</i>	Pouch below shell hinge	<i>S. plana</i>	<i>C. edule</i>	<i>H. ostralegus</i> , <i>Melanitta nigra</i> , <i>S. mollissima</i>
<i>Gymnophallus rebecqui</i>	<i>Meiogymnophallus rebecqui</i> , <i>P. isostoma</i> ?	Extrapallial space	<i>Abra ovata</i> , <i>Abra tenuis</i>	<i>C. glaucum</i> , <i>Abra tenuis</i>	Ducks (<i>Aythya</i> spp.)
<i>Gymnophallus strigatus</i>	<i>Meiogymnophallus strigatus</i> , <i>Cercaria strigata</i> , <i>Meiogymnophallus jamesoni</i> ?	Pouch below shell hinge	<i>Tellina tenuis</i>	<i>C. edule</i>	<i>M. nigra</i> ?
<i>Parvatrema isostoma</i>	–	Unencysted	<i>A. ovata</i>	<i>A. ovata</i> , <i>C. glaucum</i> ¹	Sandpipers
<i>Bucephalus minimus sensu stricto</i>	<i>Labratrema minimus</i> , <i>Labratrema lamirandi</i> , <i>Gasterostomum blanchardi</i> , <i>Dolichoenterum lamirandi</i>	Digestive gland and gonads	<i>C. glaucum</i>	<i>Atherina boyeri</i> , <i>Pomatoschistus</i> spp., <i>Liza ramada</i> , <i>L. aurata</i> , <i>Sparus aurata</i> , <i>Chelon labrosus</i>	<i>Dicentrarchus labrax</i>
<i>Bucephalus minimus sensu lato</i>	<i>Bucephalus haimeanus</i> of Lacaze-Duthiers, 1854, <i>Cercaria bucephalopsis haimeana</i> , <i>Gasterostomum gracilescens</i>	Digestive gland and gonads	<i>C. edule</i>	<i>Pomatoschistus</i> spp., <i>Pleuronectes platessa</i> , <i>Platichthys flesus</i>	Unknown

<i>Bucephalus</i> sp.	<i>Bucephalus minimus</i> of Pina <i>et al.</i> , 2009	Digestive gland and gonads	<i>C. edule</i>	<i>Mugil cephalus</i>	<i>D. labrax</i>
<i>Monorchis parvus</i>	<i>Cercaria Cerastoderma</i> I, <i>Cercaria lepidapedon racioni</i> , <i>Lepodora rachiaea</i> <i>Distoma brusinae</i>	Gonad, digestive gland, gills, foot	<i>C. edule</i> , <i>C. glaucum</i>	<i>C. edule</i> , <i>C. glaucum</i>	<i>Diplodus annularis</i> , <i>Diplodus sargus</i>
<i>Dipterostomum brusinae</i>	-	Foot, mantle border, gills	<i>N. reticulatus</i>	<i>C. edule</i>	<i>D. sargus</i>
<i>Asymphylodora demeli</i>	-	-	<i>Hydrobia</i> spp.	<i>C. glaucum</i> , <i>C. edule</i>	<i>N. diversicolor</i> , <i>Pomatoschistus</i> spp.
<i>Paratimonia gobii</i>	-	Siphon	<i>A. tenuis</i>	<i>A. tenuis</i> , <i>C. glaucum</i>	<i>P. microps</i>
<i>Leporeadum pegorchis</i>	-	-	<i>Nassarius corniculatum</i> , <i>N. mutabilis</i>	<i>C. glaucum</i>	<i>D. annularis</i> , <i>Lithognathus mormyrus</i> , <i>Pagellus erythrinus</i> , <i>Sarpa salpa</i> , <i>S. aurata</i>

¹Reported as *C. edule* by Dolgikh (1968). However, *C. edule* is absent from the Black Sea. It is therefore assumed that the report is of *C. glaucum*.

of infection is significantly higher in surfaced cockles compared with buried animals and the condition is considered a mortality driver (Villalba *et al.*, 2001; Le Grand *et al.*, 2010). The aetiological agent for disseminated neoplasias in cockles and other bivalve species has been the subject of numerous studies with suggestions that they may be due to contaminants or biotoxins (Twomey & Mulcahy, 1988; Landsberg, 1996; Barber, 2004). Transmissibility of the condition between cockles suggested an infectious agent; subsequent studies have shown evidence of a retrovirus (Twomey & Mulcahy, 1998; Collins & Mulcahy, 2003). Furthermore, Romalde *et al.* (2007) provided ultrastructural evidence of virus-like particles in the cytoplasm of neoplastic cells which they considered ‘could resemble a retrovirus-like agent’ and utilized an assay to demonstrate the presence of retroviruses in disseminated neoplasias-affected cockles. Increases in levels of the heat shock proteins Hsp 70 and Hsp 90 were noted in cockles affected by disseminated neoplasias (Díaz *et al.*, 2010). In the same study, the authors reported an increase in a 53 kDa protein analogous to mutant p53 which they considered was related to an alteration of the cell cycle.

Recently, Carrasco *et al.* (2011) reported a virosis of the epithelial cells of the digestive gland tubules. However, they were unable to unequivocally link the presence of the virosis with a mortality event in cockles from the Mediterranean coast of Spain. The lesions were noted in the digestive glands of all cockles examined by histology.

Large foci of heavy haemocyte infiltration (Figure 2B) have been linked with the presence of a putative Picornaviridae virus in *C. edule* (Carballal *et al.*, 2003). However, the authors point out that some haemocytes contain up to 4 spherical to elongate cells measuring 2–5 µm in diameter within the areas of infiltration and provide ultrastructural evidence of phagocytosed cells within host cells. It is probable that these cells are in fact developmental stages of a haplosporidian and thus the causative agent of the foci of heavy haemocyte infiltration rather than the virus. Further work is required to confirm this hypothesis.

BACTERIA AND BACTERIAL-LIKE ORGANISMS

Excluding bacteria of concern for human consumption that are acquired through feeding, a number of bacteria have been reported in cockles. Azevedo (1993) reported the presence of a *Mycoplasma*-like organism in the gills of *Cerastoderma edule* from central Portugal. Prevalence in gaping cockles was around 65 to 70% and was found ‘less frequently in living cockles’. Mortalities were attributed to a combination of the *Mycoplasma*-like organisms and high water temperatures (Azevedo, 1993). The cytoplasm of infected cells showed evidence of lysis and contained pyknotic nuclei, few mitochondria, no ribosomes and numerous vacuoles. The infection has not been reported since.

Brown ring disease (BRD) caused by *Vibrio tapetis* Borrego, Castro, Luque, Paillard, Maes, Garcia & Ventossa, 1996 is a shell disease occurring predominately in clams (*Ruditapes* spp.) (Paillard *et al.*, 1994). However, despite the bacteria being isolated from several species of bivalves, mortalities in the wild are only recorded in the Manila clam (Paillard, 2004). Under experimental conditions, mortality of cockles was 100% (Paul-Pont *et al.*, 2010); in the wild the bacteria

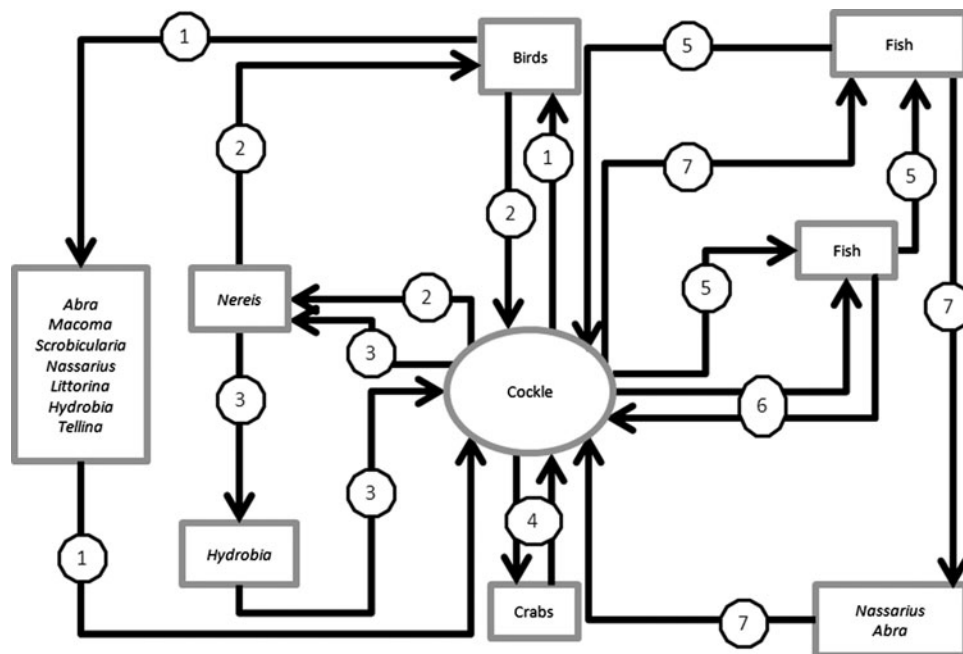


Fig. 1. Life cycle patterns of cockle parasites that involve more than one host. It does not include infections transmitted between cockles such as viruses and bacteria. Where line 1 includes *Himasthla continua*, *H. elongata*, *H. interrupta*, *H. quissetensis*, *Renicola roscovita*, *Psilostomum brevicolle*, *Gymnophallus fossarum*, *G. gibberosus*, *G. minutus*, *G. rebecqui* and *G. strigatus*; line 2 includes *G. choleodochus*; line 3 includes *Asymphylodora demeli*; line 4 includes *Nematopsis* sp.; line 5 includes *Bucephalus* spp.; line 6 includes *Monorchis parvus* and line 7 includes *Diptherostomum brusinae*, *Paratimonia gobii* and *Lepocreadium pegorchis*.

does not appear to induce mortalities (Paillard *et al.*, 1994; Lassalle *et al.*, 2007). Despite high concentration of bacteria in cockles, their role in transmitting the bacteria to naïve clams and the subsequent manifestation of BRD is unknown.

Symbiotic bacteria occurring in the epithelial cells of a number of hosts have been reported either as *Rickettsia*-like organisms (RLOs) or *Chlamydia*-like organisms (CLOs) (Cajaraville & Angulo, 1991) and have occasionally been reported as causing mortality in a range of hosts (Sun & Wu, 2004; Nowak & LaPatra, 2006; Horn, 2008). RLOs in the gills and CLOs in the digestive gland epithelial cells (Figure 2C) of *C. edule* from Spain have been described but with limited pathological changes noted (Carballal *et al.*, 2001; Ordás & Figueras, 2005). An additional, unclassified extracellular bacteria-like organism was reported in the gills and mantle (Figure 2D) of around 40% of edible cockles from Galicia (Carballal *et al.*, 2001). The cysts, which altered gill architecture, were generally larger than those reported for RLOs and CLOs in the same animals (Carballal *et al.*, 2001). Similar extracellular cysts have been reported in oysters with limited pathology and mortality (Azevedo & Villalba, 1991).

Changes in burrowing behaviour or survival of cockles during low tide have been attributed to a number of factors including the presence of bacteria and it has been suggested that anaerobic pathogenic bacteria intimately associated with cockles may be responsible for some of the mortalities observed (de Zwaan *et al.*, 2002). Indeed, the addition of broad-spectrum antibiotics that target gram-positive bacteria can increase cockle survival time two-fold under anoxic conditions (Babarro & de Zwaan, 2001, 2008). Blanchet *et al.* (2003) considered that the marine bacteria *Pseudomonas fluorescens* (Flügge, 1886) triggered the emergence of cockle

from the sediment but that such action did not lead directly to the death of the affected animals.

FUNGI

Fungal infections of cockles have been rarely reported. Bowmer *et al.* (1994) reported the presence of branched fungal hyphae in the epithelial cells of the digestive gland of *Cerastoderma edule* leading to oedema and subsequent degeneration of the digestive gland. No further details were provided and its relationship to *Leptolegniella* (= *Leptolegnia*) *marina* (Atkins, 1954) reported from a solitary *Acanthocardia echinata* (Linnaeus, 1758) is unknown (Atkins, 1954).

Microsporidia, previously considered to be protists, are now considered to be fungi (Hirt *et al.*, 1999; Fischer & Palmer, 2005; Gill & Fast, 2006). A brief report of an unidentified microsporidian in the digestive gland epithelium of *C. edule* in France was provided by Comps *et al.* (1975). Spores measured 2.5 × 1.5 µm and had 4 turns to the polar filament; the absence of other stages in the host precluded a full description. Comps *et al.* (1975) suggested that the infection was unlikely to be a major contributory factor in cockle mortalities as it occurred at low prevalence (10%) with limited pathology associated with infection.

A *Steinhausia* sp. (Microsporidia) was noted in the oocytes (Figure 2E) of 2 *C. edule* collected from 2 sites in Galicia, north-west Spain with no significant pathology recorded (Carballal *et al.*, 2001). Cysts measured about 18 µm in length and contained spores measuring approximately 1.5 µm in diameter. A second, slightly larger *Steinhausia* sp. measuring 2–3 µm in diameter has been reported from cockles from Baie des Veys, France (Comtet *et al.*, 2003).

Table 2. Summary of parasites/diseases/commensals reported in *Cerastoderma edule* and *C. glaucum*. Where: – No effect recorded or negligible impact; + Localised pathology, limited effect on survival; ++ Individual mortality or impact on growth, metabolism; +++ Population level effect, mass mortalities reported.

	Taxa	Species/name	Host		Impact
			<i>C. edule</i>	<i>C. glaucum</i>	
1	Virus	Disseminated neoplasia	Y	Y	+++
2	Bacteria	<i>Mycoplasma</i> -like	Y	N	+++
3	Bacteria	<i>Vibrio tapetis</i>	Y	N	+
4	Bacteria	<i>Rickettsia</i> -like organisms	Y	N	+
5	Bacteria	<i>Chlamydia</i> -like organisms	Y	N	+
6	Bacteria	Extracellular bacteria-like organisms	Y	N	+
7	Fungi	Fungi of Bowmer <i>et al.</i> , 1994	Y	N	–
8	Microsporidia	<i>Steinhausia</i> sp.	Y	N	+
9	Microsporidia	Microsporidia of Comps <i>et al.</i> , 1975	Y	N	+
10	Microsporidia	<i>Unikaryon legeri</i> in <i>G. minutus</i>	Y	N	–
11	Apicomplexa	<i>Nematopsis portunidarum</i>	Y	Y	+
12	Apicomplexa	<i>N. schneideri</i>	Y	N	++
13	Apicomplexa	<i>N. incognito</i>	N	Y	++
14	Apicomplexa	<i>Pseudoklossia</i> sp.	Y	N	–
15	Amoeba	Unidentified amoeba	Y	N	+++
16	Ciliophora	<i>Hypocomella raabei</i>	Y	Y	–
17	Ciliophora	<i>Sphenophyra cardii</i>	Y	Y	–
18	Ciliophora	<i>Hypocomidium fabius</i>	Y	Y	–
19	Ciliophora	<i>Trichodina cardii</i>	Y	N	–
20	Ciliophora	<i>T. polandiae</i>	N	Y	–
21	Ciliophora	<i>T. cardiorum</i>	N	Y	–
22	Perkinsozoa	<i>Perkinsus</i> sp.	Y	Y	+
23	Haplosporidia	<i>Haplosporidium edule</i>	Y	N	+
24	Haplosporidia	<i>Minchinia tapetis</i>	Y	N	+++
25	Haplosporidia	<i>M. mercenariae</i>	Y	N	+++
26	Haplosporidia	<i>Urosporidium</i> sp. in <i>Paravortex cardii</i>	Y	N	–
27	Cercozoa	<i>Marteilia</i> sp.	Y	N?	+++
28	Turbellaria	<i>Paravortex cardii</i>	Y	Y	–
29	Turbellaria	<i>P. karlingi</i>	Y	N	–
30	Digenea	<i>Bucephalus</i> sp. of Matthews, 1973	Y	N	+++
31	Digenea	<i>Bucephalus minimus</i>	N	Y	++
32	Digenea	<i>Bucephalus</i> sp. of Pina <i>et al.</i> , 2009	Y	N	–
33	Digenea	<i>Himastha elongata</i>	Y	Y	++
34	Digenea	<i>H. interrupta</i>	Y	Y	++
35	Digenea	<i>H. continua</i>	Y	Y	++
36	Digenea	<i>H. quissetensis</i>	Y	Y	++
37	Digenea	<i>Curtuteria arguiniae</i>	Y	N	–
38	Digenea	<i>Gymnophallus choledochus</i>	Y	Y	+++
39	Digenea	<i>G. gibberosus</i>	Y	Y	+++
40	Digenea	<i>G. fossarum</i>	Y	Y	+
41	Digenea	<i>G. minutus</i>	Y	N	+++
42	Digenea	<i>G. strigatus</i>	Y	N	+
43	Digenea	<i>G. rebecqui</i>	N	Y	+
44	Digenea	<i>G. isostoma</i>	N	Y	–
45	Digenea	<i>Asymphylogora demeli</i>	Y	Y	–
46	Digenea	<i>Monorchis parvus</i>	Y	Y	+++
47	Digenea	<i>Paratimonia gobii</i>	N	Y	–
48	Digenea	<i>Lepocreadium pegorchis</i>	N	Y	–
49	Digenea	<i>Psilostomum brevicolle</i>	Y	Y	–
50	Digenea	<i>Renicola roscovita</i>	Y	Y	–
51	Digenea	<i>Diptherostomum brusinae</i>	Y	N	–
52	Digenea	<i>Parorchis acanthus</i>	Y	N	–
53	Cestoda	<i>Anatinella brachycephala</i>	Y	N	–
54	Nematoda	Unidentified	Y	Y	–
55	Crustacea	<i>Herrmanella rostrata</i>	Y	N	–
56	Crustacea	<i>Mytilicola intestinalis</i>	Y	N	+
57	Crustacea	<i>Pinnotheres pisum</i>	Y	N	–
58	Crustacea	<i>Afropinnotheres monodi</i>	N	Y	–
59	Nemertea	<i>Malacobdella grossa</i>	Y	N	–

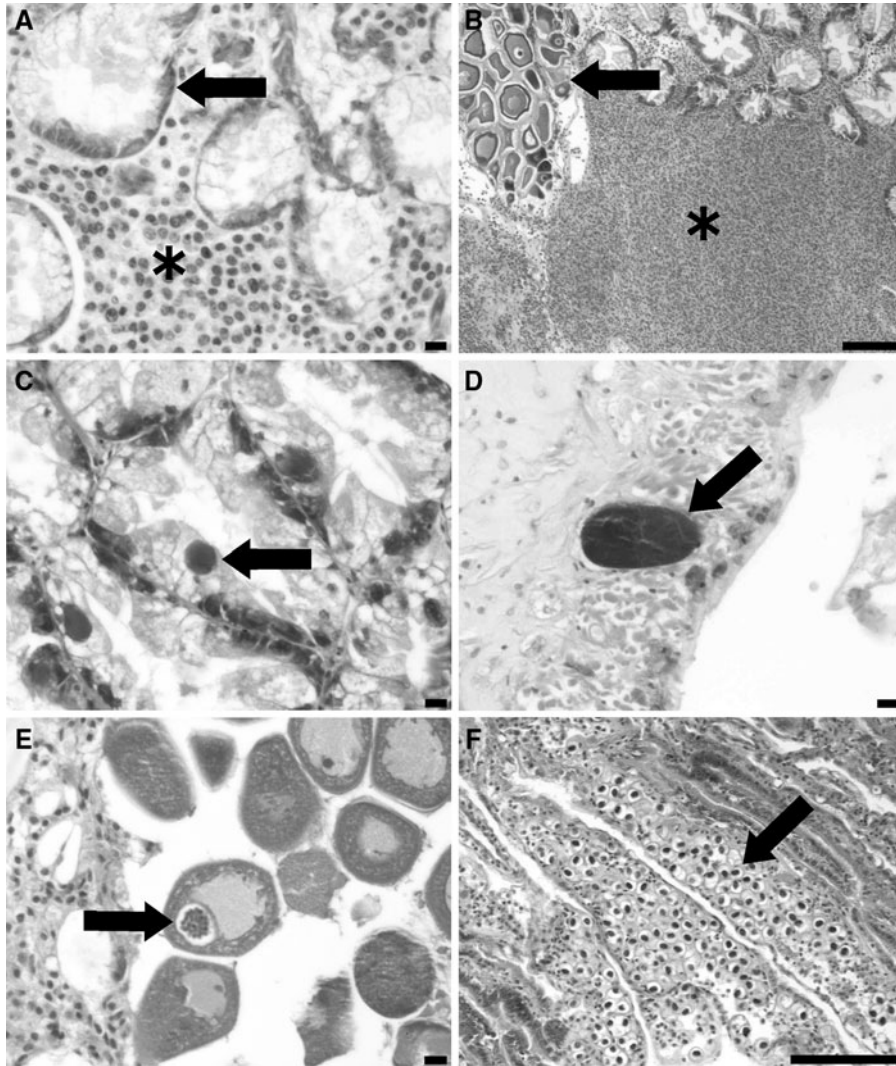


Fig. 2. Histopathology of infections of *Cerastoderma* spp.: (A) disseminated neoplasias infection showing affected cells (*) in the connective tissue surrounding digestive gland tubules (arrow); (B) large foci of heavy haemocyte infiltration (*) in connective tissue. Note presence of ovaries (arrow); (C) *Chlamydia*-like organisms (CLOs) (arrow) in the digestive gland tubule epithelial cells. Note the lack of host response to the infection; (D) large extracellular bacterial-like organism (arrow) of the mantle; (E) *Steinhausia* sp. (arrow) infection of the ovocyte with no obvious associated pathology; (F) *Nematopsis* sp. (arrow) infection in the gills of cockle. Scale bars for A, C, D and E = 10 μ m; B and F = 100 μ m. Histological sections stained with haematoxylin and eosin (H&E).

Intensity of infection was generally low and unlike some species of *Steinhausia*, pathological changes associated with the parasite were limited (Anderson *et al.*, 1995). Although prevalence was significantly higher in surfaced cockles compared with buried cockles (11% versus 20%), the unequivocal role of the parasite in mortalities was unclear (Comtet *et al.*, 2003). These parasites require further characterization and discrimination from related *Steinhausia* spp.

Unikaryon (= *Nosema*) *legeri* (Dollfus, 1912) (Microsporidia) (Figure 5B), is a hyperparasite of the tissues of the digenean *Gymnophallus* (= *Meiogymnophallus*) *minutus* (Cobbold, 1859). Infection levels of *U. legeri* in *G. minutus* increase with increasing size and age of cockles, peaking in *G. minutus* in 2–3 year old cockles (Goater, 1993; Fermer *et al.*, 2009). Subsequent loss of *U. legeri* infections from *G. minutus* of older cockles is attributed to hyperparasite-induced death of the digenean host with *U. legeri* being considered to be a major mortality driver for *G. minutus* (Goater, 1993; Fermer

et al., 2009). Whilst the hyperparasite can be detected throughout the year in its digenean host, transmission is restricted to spring and summer and is strongly correlated to water temperature (Fermer *et al.*, 2010). The complete life cycle of *U. legeri* has not yet been fully elucidated although it appears to be restricted to the metacercarial stages of *G. minutus* in cockles (Fermer *et al.*, 2009). Following inhalation of spores by the cockle, host transmission between metacercariae leads to the development of paired spores occurring within a sporophorous vesicle (Canning & Nicholas, 1974; Azevedo & Canning, 1987). The hyperparasite has no direct impact on the cockle.

PROTISTA—PHYLUM APICOMPLEXA

Gregarines of the genus *Nematopsis* undergo sporogony in lamellibranch molluscs and have a vegetative and

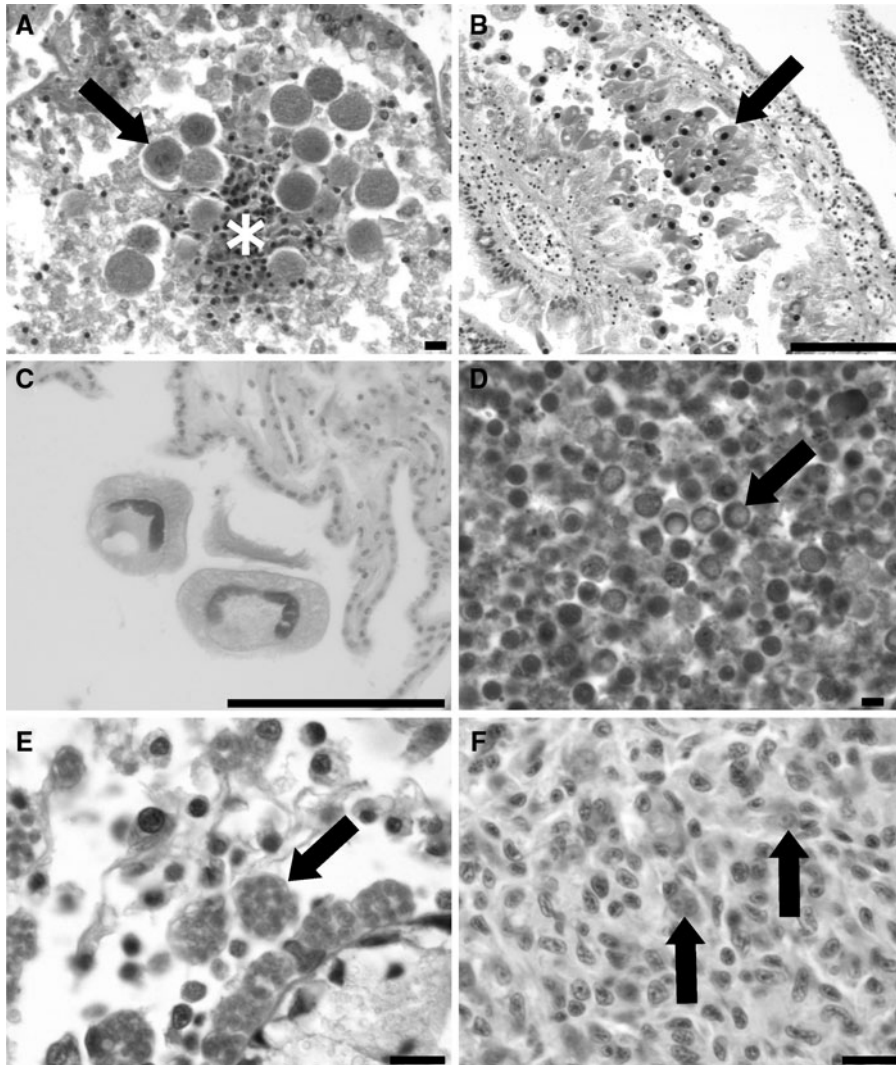


Fig. 3. Histopathology of infections in *Cerastoderma* spp.: (A) *Pseudoklossia* sp. infection of the kidney (arrow). Note loss of infected cells and haemocyte infiltration (*) associated with presence of gamont and oocyst stages; (B) aggregation of *Hypocomella raabei* (arrow) in the gills of *Cerastoderma* sp. with typical dark stained nucleus apparent in most individuals; (C) cross-section through three individual *Trichodina* sp. on the gills; (D) trophozoites of *Perkinsus* sp. (arrow); (E) plasmodia containing developing spores of *Haplosporidium edule* (arrow) in the connective tissue of edible cockle; (F) high power view of large foci of heavy haemocyte infiltration in Figure 2B. Several haemocytes containing numerous single celled organisms are apparent (arrows). Scale bars for A, D, E and F = 10 μm ; B and C = 100 μm . Histological sections stained with haematoxylin and eosin (H&E).

reproductive phase in marine decapod crustaceans (Clopton, 2002) although the life cycles of *Nematopsis* spp. occurring in cockles have not been fully elucidated (Figure 2F). Whilst pathogenicity associated with members of the genus are inconclusive, Azevedo & Cachola (1992) considered that a mortality of Portuguese *Cerastoderma edule* was possibly due to a *Nematopsis* sp. The parasite caused lysis of the tissues of cockles leading to 'complete destruction of the gill cells in the immediate area in contact with the oocyst'. Prevalence is generally higher in the summer months and more intense in larger specimens (Azevedo & Cachola, 1992). At least 30 *Nematopsis* species have been described from bivalves worldwide (Belofastova, 1996), including *N. portunidarum* (Frensel, 1885) and *N. schneideri* Léger, 1903 in *C. edule* and *N. incognito* Belofastova, 1996 and *N. portunidarum* in *C. glaucum* (van Banning, 1979; Azevedo & Cachola, 1992; Soto *et al.*, 1996; Belofastova & Dmitrieva, 1999; Ordás & Figueras, 2005).

Low level infections by an unidentified coccidian were noted in cockles from Portugal with light to moderate lesions in the kidney tubules (Carballal *et al.*, 2001). All developmental stages were noted in affected hosts suggesting that life cycle was direct. Hypertrophy of the renal cells coupled with a localized haemocytic response is typical with subsequent loss and disruption of infected cells in heavy infections. Carballal *et al.* (2001) considered that these heavy infections had the potential to cause renal dysfunction. To date no adequate description of the kidney-infecting coccidian of cockles has been provided (Ghimire, 2010) although it is likely to be a *Pseudoklossia* sp. (Figure 3A).

PROTISTA—FAMILY AMOEBIDAE

An unidentified amoeba, measuring 18–20 μm in diameter, was described from the sub-epithelial gill tissues of

Cerastoderma edule from Portugal (Azevedo, 1997). The amoeba was associated with haemocytic infiltration and necrosis of host cells. Affected cockles were found gaping at the surface and the infection was considered to be responsible for a mass mortality event of cockles (Azevedo, 1997). It has not been reported since.

PROTISTA—PHYLUM CILIOPHORA

In general, ciliates from cockles have been poorly described with few recent studies reporting below the level of genus or even family (Carballal *et al.*, 2001; Ordás & Figueras, 2005). Typically ciliates have not been associated with mortalities in cockles. They generally occur on the gills and mantle surfaces of cockles and detailed descriptions of ciliates in cockles provided by Fenchel (1965). These include *Hypocomella raabei* (= *cardii*) Chatton & Lwoff, 1950 (Figure 3B), *Sphenophyra cardii* Chatton & Lwoff, 1950, *Hypocomidium fabius* Raabe, 1938 on the gills of *Cerastoderma glaucum* and *C. edule*. In addition, trichodinids, which typically inhabit external surfaces of aquatic animals have been reported on cockles (Figure 3C) including *Trichodina cardii* from *C. edule* and *Trichodina polandiae* (= *T. domergui* f. *cardii*) Fenchel, 1965 and *T. cardiorum* Raabe & Raabe, 1959 from *C. glaucum*. Fenchel (1965) also reported the presence of unidentified species of *Trichodina* and thus it is likely that several species exist.

PROTISTA—PHYLUM PERKINSOZOA

Perkinsus sp. hypnospores (Figure 3D), measuring between 16 and 45 µm in diameter, were reported at prevalences of up to 28% in *Cerastoderma glaucum* from St Gilla Lagoon, Sardinia (Culurgioni *et al.*, 2006; Figus *et al.*, 2006). As hypnospores were obtained through culturing of mantle and gill pieces in thioglycollate solution, no information was provided on pathological responses in the host. The parasite is apparently absent from cockles from Galicia (Villalba *et al.*, 2001) but has been reported in *C. edule* from the French Atlantic coast at an average prevalence of 33% (range 3 to 67%). Density was estimated at around 36 cells g⁻¹ tissue, although maximum observed was 103 cells g⁻¹ tissue in cockles from Oléron (Lassalle *et al.*, 2007). Whilst mortalities have been associated with *Perkinsus* spp. in other bivalve hosts, to date, no information has been provided on the impact of the parasite on cockle populations. The parasite in cockles remains to be properly described and adequately discriminated from pathogenic species.

PROTISTA—PHYLUM HAPLOSPORIDIA

Different stages of the haplosporidian *Haplosporidium edule* Azevedo, Conchas & Montes, 2003 (Figure 3E), have been described from various tissues of *Cerastoderma edule* from Spain by Azevedo *et al.* (2003). Spores, measuring approximately 3 × 2 µm, have bifurcated projections and a large number of folds to the wall. Plasmodia, sporonts and sporocysts occur in the connective tissue of the gills,

mantle and gonad, and predominately in the digestive gland. A strong haemocytic response is noted, particularly towards plasmodial stages and sporogony is asynchronous (Carballal *et al.*, 2001). No data exist on the impact of this haplosporidian on cockle survival although given the strong inflammatory response throughout the tissues it is likely to be detrimental.

Large foci of heavy haemocyte infiltration have been reported in *C. edule* from Spain (Carballal *et al.*, 2001; Villalba *et al.*, 2001). Prevalence was up to 88% and led to loss of normal architecture and destruction of organs and tissues in infected animals (Villalba *et al.*, 2001). Carballal *et al.* (2003) considered that a member of the picornaviridae was involved in the production of the condition based on ultrastructural studies. Virus-like particles were detected in paracrystalline arrays in the cytoplasm of infected cells. However, in all reports of the condition, the authors also report the presence of up to 4 unidentified cells measuring 2–5 µm in diameter within haemocytes in these foci (Figure 3F) (Carballal *et al.*, 2001, 2003; Villalba *et al.*, 2001). Preliminary data from The Netherlands and the UK strongly implicate *Minchinia tapetis* (Vilela, 1951) and *M. mercenariae* Ford, Stokes, Burreson, Scarpa, Carnegie, Kraeuter & Bushek, 2009 in the formation of these lesions (Engelsma *et al.*, 2011; Longshaw & Engelsma, unpublished data) originally described from their respective natural hosts, *Ruditapes decussatus* (Linnaeus, 1758) and *Mercenaria mercenaria* (Linnaeus, 1758) by Navas *et al.* (1992), Burreson & Ford (2004) and Ford *et al.* (2009). The host specificity of *M. tapetis* is questionable as it has also been reported in *Ruditapes philippinarum* (Adams & Reeve, 1850) and *Venerupis aurea* (Gmelin, 1791) by Navas *et al.* (1992). Further characterization, such as molecular methods, of cells involved in the lesions in cockles is required to confirm the role of these haplosporidians in the condition.

Carballal *et al.* (2005) have reported the presence of a *Urosporidium* sp. in the connective tissue of a single *Paravortex cardii* Hallez, 1908 from the lumens of *C. edule*. The authors were unable to discriminate the hyperparasite from others within the genus and suggested that further characterization was required. Its impact on *P. cardii* and its ability to infect cockles is unknown although it does not appear to be directly harmful to cockles.

PROTISTA—PHYLUM CERCOZOA

Marteilia species have been associated with mortality in a number of bivalve hosts and the discrimination of species requires the use of both molecular and ultrastructural data (Novoa *et al.*, 2005; Thébault *et al.*, 2005; López-Flores *et al.*, 2008; Feist *et al.*, 2009). Comps *et al.* (1975) provided a brief description of a *Marteilia* sp. in the digestive gland of *Cerastoderma edule* from the Brittany region of France which they were unable to discriminate from *M. refringens* Grizel, Comps, Bonami, Cosserans, Duthoit & Le Pennec, 1974; prevalence was approximately 10% (Figure 4A). A second report of the parasite in three populations of cockles from the same region was made by Auffret & Poder (1987) although no description was provided and prevalence was reported as 'low'.

Carrasco *et al.* (2011) reported on a mass mortality event of edible cockles on the Mediterranean coast of Spain, with a

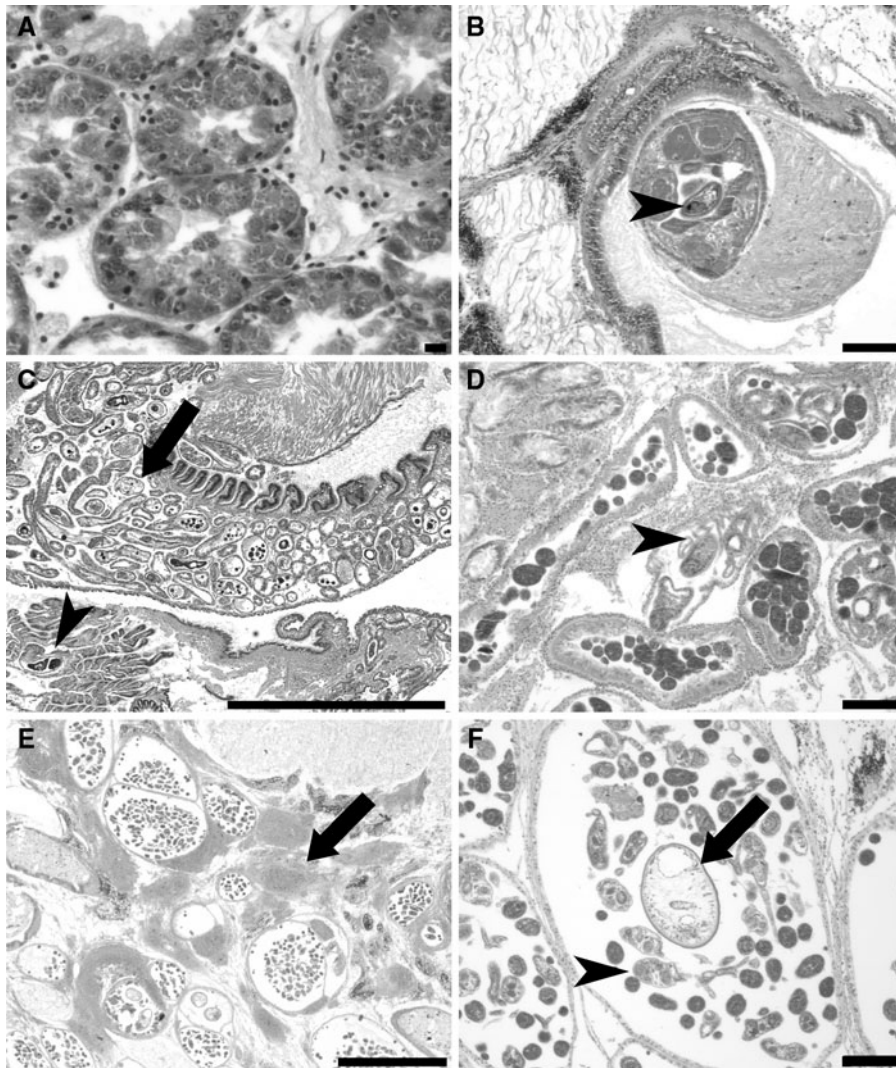


Fig. 4. Histopathology of infections in *Cerastoderma* spp.: (A) histological section through digestive gland showing the presence of *Marteilia* sp. in the epithelial cells. Note large primary cell containing numerous secondary and tertiary cells; (B) *Paravortex karlingi* in the intestine of *Cerastoderma* sp. with numerous developmental stages, including one with obvious eyespots (arrowhead); (C) low power view of edible cockle with heavy infection with *Bucephalus minimus sensu lato*. Note presence of parasite sporocysts both within the gill (arrowhead) and mantle and gonad (arrow); (D) high power view of *B. minimus sensu lato* sporocysts with containing developing cercaria with obvious furcae (arrowhead). Note asynchronous development of other sporocysts nearby containing early germ cells only; (E) low power view of *Gymnophallus choleodochus* infection with marked inflammatory response to sporocysts (arrow); (F) sporocysts of *G. choleodochus* containing both developing cercaria (arrowhead) and metacercaria (arrow). Scale bars for A = 10 μm ; B, D and F = 100 μm ; C and E = 1 mm. Histological sections stained with haematoxylin and eosin (H&E).

Marteilia sp. being noted in around 40% of the animals examined during 2008. The authors acknowledged that they could not unequivocally link the presence of the parasite to the mortality event in light of the comparatively low prevalence of infection. However, they did argue that the relatively moderate to high intensity of infection coupled with the presence of other stressors may have contributed to the mortality event. Subsequently Carrasco *et al.* (2012) revisited the site of the 2008 mortality event and collected samples for molecular studies. Prevalence of infection was much lower (23% in May 2010 and 1.7% in June 2010) compared with previous years. Molecular characterization of the cockle parasite demonstrated that the parasite showed around 85% homology of the internal transcribed spacer 1 (ITS-1) and intergenic spacer (IGS) with *M. refringens* from oysters and mussels and the authors consider that the parasite is a new genotype. Ultrastructural studies are required to further discriminate the

parasite in cockles from *M. refringens* reported in other European bivalves. Furthermore, studies on the life cycle of the parasite, similar to those completed for *M. refringens* would need to be conducted to further understand its potential to spread and affect other cockle beds (Audemard *et al.*, 2002; Carrasco *et al.*, 2008; López-Flores *et al.*, 2008). In addition, confirmation of the species of cockle infected would need to be completed as *C. edule* rarely occurs in the Mediterranean Sea and thus it is possible that the cockles examined were in fact *C. glaucum*.

PHYLUM PLATYHELMINTHES— CLASS TURBELLARIA

Turbellaria are generally considered to be commensals of a number of molluscs, being able to freely move from the

mantle cavity of the mollusc to the alimentary canal and do not generally cause a problem for the host. *Paravortex cardii* occurs in both *Cerastoderma edule* and *C. glaucum* with *C. edule* also being host to *P. karlingi* Pike & Burt, 1981 (Figure 4B). Brusa *et al.* (2006) lists *C. edule* as a host for *P. gemellipara* (Linton, 1910) citing the record of Leigh-Sharpe (1933) from cockles in Plymouth, UK. However, *P. gemellipara* is an endocommensal of bivalves from the eastern Atlantic Ocean and thus the report is considered dubious at best. Furthermore, Atkins (1934), also working in Plymouth retracted his earlier record of *P. gemellipara* in cockles (Atkins, 1933) stating that his form in Plymouth and that of Leigh-Sharpe (1933) was clearly *P. cardii*. The record of a 'ciliated sporocyst' in *C. edule* by Nicoll (1906) is likely to be *P. cardii*. *Paravortex cardii* is approximately twice the size of *P. karlingi* and has three times as many brood capsules as *P. karlingi*. *Paravortex cardii* is restricted to the digestive gland tubules, whilst *P. karlingi* occurs in the intestine of its host. Pike & Burt (1981), in describing *P. karlingi*, showed that both species were widespread throughout the UK. *Paravortex cardii* has been recorded in edible and lagoon cockles in the Baltic Sea, Wadden Sea, Black Sea, Mediterranean Sea, France, Spain and Morocco (Belofastova & Dmitrieva, 1999; de Montaudouin *et al.*, 2000; Carballal *et al.*, 2001; Zander & Reimer, 2002; Culurgioni *et al.*, 2006; Thieltges *et al.*, 2006; Gam *et al.*, 2008).

PHYLUM PLATYHELMINTHES— CLASS TREMATODA

Cockles are hosts to a wide range of digeneans (trematodes), some of which have been implicated in mortality events or in reducing growth or fecundity. Identification keys to trematodes occurring in *Cerastoderma edule* are provided by de Montaudouin *et al.* (2009). Typically digenean life cycles are complex with eggs released from adult stages producing free-swimming ciliated miracidia that infect the first intermediate host, normally a mollusc. This develops into a mother sporocyst within the first intermediate host with further development into either daughter sporocysts or redia, depending on species. A further asexual phase takes place with the production of cercaria which is infective to the second intermediate host. Cockles can act as either first or second intermediate host, depending on the species of digenean. Once in the second intermediate host, cercaria develops into metacercaria before transmission to the final host where they undergo sexual reproduction followed by release of eggs into the environment.

One of the main Digenea reported as causing castration and death of cockles occurs in the genus *Bucephalus* (family Bucephalidae). The taxonomic history of bucephalids in cockles (and other bivalves) is somewhat confused, leading to some erroneous records and complications with the nomenclature. A detailed historical account of the family is provided by Kniskern (1952) and Overstreet & Curran (2002). *Bucephalus haimeanus* (Lacaze-Duthiers, 1854) was described from *Ostrea edulis* (Linnaeus, 1758) and *Acanthocardia tuberculata* (Linnaeus, 1758) (originally reported as *Cardium rusticum*) collected at Mahon on the Balearic Islands and Sète on the French coast (Mediterranean Sea) respectively (Lacaze-Duthiers, 1854). Due to misinterpretations by various authors, cercaria in a variety of bivalve hosts have been referred to as *B. haimeanus*, including those occurring in European

Cerastoderma spp. as well as the cercaria of *B. cuculus* McGrady, 1873 from *Crassostrea gigas* (Thunberg, 1793) collected in the United States of America (Tennent, 1906; Hopkins, 1954; Cheng & Burton, 1965). *Bucephalus haimeanus sensu stricto* is a parasite of *O. edulis* (Princep & Durfort, 1993; Princep *et al.*, 1996); the digenean reported as *B. haimeanus* in *A. tuberculata* by Lacaze-Duthiers (1854) requires redescription and reports of the parasite in other European bivalves are incorrect.

Subsequently, Stossich (1887) described *B. minimus* Stossich, 1887 from the intestine of *Dicentrarchus labrax* (Linnaeus, 1758) caught off Trieste in the Adriatic Sea as *Gasterostomum minimum*. Several nomenclatural changes followed culminating in the description of *Labratrema lamirandi* (Maillard, 1975) as a new species by Maillard (1975b) from the intestine of *D. labrax*. However, Maillard & Saad-Fares (1981) later listed *B. lamirandi* as a junior synonym of *B. minimus*. Overstreet & Curran (2002) did not refer to this work and, whilst correctly proposing that *Labratrema* should be a junior synonym of *Bucephalus*, they considered that *B. lamirandi* was a *species inquirendae*. Maillard (1975b), in completing the life cycle of *B. minimus*, showed experimentally that it cycled from *C. glaucum* as a first host, through several fish species as second intermediate hosts and used *D. labrax* as the final host. The proposed life cycle for the *C. glaucum* bucephalid has subsequently been confirmed by other workers (Faliex & Morand, 1994; Faliex *et al.*, 2003).

Cercaria in *C. glaucum* have a flame cell arrangement of 2 [(6 + 6 + 6) + (6 + 6 + 6)] = 72 and measure 200–350 μm \times 80–100 μm with the furcae measuring approximately 350 μm . The parasite has been reported in *C. glaucum* at various locations within the Mediterranean Sea (Faliex & Morand, 1994; Faliex *et al.*, 2003; Culurgioni *et al.*, 2006; Bartoli & Gibson, 2007). Based on the life cycle data, morphological characteristics and its geographical location (Mediterranean Sea, close to the type locality of *B. minimus* from sea bass), it is proposed that the bucephalid occurring in *C. glaucum* be referred to as *Bucephalus minimus sensu stricto* (Stossich, 1887).

A second bucephalid parasite has been reported from *C. edule* in the UK (Lebour, 1912; Cole, 1956; James *et al.*, 1966; Bowers, 1969; Matthews, 1973), The Netherlands (Thieltges & Reise, 2006; Thieltges *et al.*, 2006; 2008; Engelsma *et al.*, 2011), France (Huet, 1888; Pelseneer, 1906; Deltreil & His, 1970; de Montaudouin *et al.*, 2000; Blanchet *et al.*, 2003), Spain (Carballal *et al.*, 2001; Ordás & Figueras, 2005), and Morocco (Gam *et al.*, 2008). To date only part of the life cycle has been experimentally completed with the parasite being transmitted from naturally infected *C. edule* to *Pomatoschistus microps* (Krøyer, 1838) by Matthews (1973). Matthews (1973), referring to the parasite as *Cercaria bucephalopsis haimeana* of Lacaze-Duthiers (1854), suggested that *Pleuronectes platessa* Linnaeus, 1758 were accidental hosts as only juvenile plaice could be infected and that the majority of the parasites did not survive beyond 2 weeks in the flatfish host. It was suggested that the final host was *D. labrax* based on 'comparative morphology and ecology of the host'. Matthews (1973) described the cercaria as measuring 480 \times 40 μm when elongate, 100 μm when contracted, with an average measurement of 200 \times 50 μm . Flame cell arrangement is 2 [(3 + 3 + 6 + 6 + 3) + (4 + 4 + 3)] = 64; Matthews (1973) erroneously totalled the number of flame

cells as 60. The furcae are up to ten times longer than the body, measuring up to 2 mm in length.

The measurements and flame cell arrangement provided by Matthews (1973) are at odds with those provided by Maillard (1975b) and provide strong circumstantial evidence that the parasite occurring in *C. edule* appears to be morphologically distinct from *B. minimus* occurring in *C. glaucum* from the Mediterranean. Whilst there is compelling evidence to suggest that the bucephalid occurring in *C. edule* in northern Europe is a distinct species, until a complete redescription of bucephalids of *Cerastoderma* spp. is completed, it is suggested that the bucephalid in *C. edule* be designated as *Bucephalus minimus sensu lato*. Furthermore, there appear to be some differences in life cycle strategies, size and morphology between the bucephalids described from European edible cockles by several authors in Europe and the bucephalid reported by Russell-Pinto *et al.* (2006) and Pina *et al.* (2009a) in Portugal leading to the possibility that more than one form of *B. minimus sensu lato* exists. Other than the molecular approach of Pina *et al.* (2009a) and the partial experimental studies of Matthews (1973), no comparative or life cycle studies have been carried out on bucephalids in *C. edule* and thus there is an urgent need to reassess the biology, ecology and taxonomy of these parasites.

Bucephalus spp. infect all tissues of *C. edule* and *C. glaucum* with a focus in the gonads and gills (Figure 4C, D). In heavy infections, parasitic castration of the host is apparent (Carballal *et al.*, 2001; Culurgioni *et al.*, 2006). Destruction of the gonadal tissue follows disintegration of the connective tissues surrounding it. James & Bowers (1967a) suggest that this may be due to release of hyaluronidase and pressure atrophy by the parasite. Following destruction of the gonad, the growing parasite appears to block or crush the digestive tubules leading to starvation autolysis of the digestive gland. Breakdown of the digestive tubules ensues as a result of a combination of the physiological effects of the parasite, pressure atrophy due to the growing daughter sporocyst and loss of fluids from the tubule cells. Distribution of lipids, carbohydrates and enzymes were determined by James & Bowers (1967b) which they suggested was similar to previous reports and was mainly derived from host tissues. Use of stable isotopes confirmed that the parasite derived its energy from the digestive gland and had a preference for lipids (Dubois *et al.*, 2009). Energy stored in cockles in the form of glucose, glycogen and lipids is potentially utilized by the parasite in the migration between hosts.

Intensity of infection in individual animals can be high and prevalence in the population is variable. In the Burry Inlet, South Wales, infections were only detected in post-spawning cockles that were greater than a year old and larger than 18 mm in length by Bowers (1969). Furthermore, Bowers (1969) suggested that reductions in parasite prevalence in cockles greater than 3 years old was due to parasite-induced host mortality and increased resistance of older cockles to infection. Infected cockles had a lowered shell growth rate but an increased flesh yield. Prevalence of infection in *C. edule* and *C. glaucum* increases steadily throughout the summer months, decreasing in the autumn as a result of availability of suitable host(s) (Bowers, 1969; Faliex & Morand, 1994; Desclaux *et al.*, 2002; Faliex *et al.*, 2003). Spatial variations in prevalence perhaps reflect local hydrological conditions, host availability and other factors. Prevalence figures for *Bucephalus* spp. in *C. edule* and *C. glaucum* across their

range in Europe tend to follow similar patterns, ranging from <1% to around 40% (Deltreil & His, 1970; de Montaudouin *et al.*, 2000, 2009; Carballal *et al.*, 2001; Desclaux *et al.*, 2002; Ordás & Figueras, 2005; Culurgioni *et al.*, 2006; Russell-Pinto *et al.*, 2006; Thieltges & Reise, 2006; Thieltges *et al.*, 2006; Gam *et al.*, 2008). Cole (1956) reported prevalences of around 2% for the parasite in *C. edule* from North Wales in the 1950s; prevalence was around 15% in cockles from South Wales in the early 1960s (Bowers, 1969); prevalences in *C. edule* and *C. glaucum* from the River Crouch in the late 1960s were 12% and 0.04% respectively (Boyden, 1970, 1971). Boyden (1970) considered the infection in the solitary *C. glaucum* as accidental with 'infection of *C. glaucum* only occurring in exceptional circumstances'.

Cerastoderma edule infected with *B. minimus sensu lato* tend to have fewer parasites, although the mechanism for this is not understood (de Montaudouin *et al.*, 2000; Desclaux *et al.*, 2002). Desclaux *et al.* (2002) showed that prevalence of infection in surfaced cockles was approximately twice that of buried cockles. They calculated that around 10% of surfaced cockles did so as a direct result of infections with this parasite but were unable to explain the advantage to the parasite of this strategy given the route of infection to the next host via free swimming cercariae. Deltreil & His (1970) suggested that death of infected animals at the surface facilitated dispersion of the cercariae. However, *C. edule* infected with *B. minimus sensu lato* have a lower specific oxygen consumption rate with a decrease in specific pumping rate and are less able to adapt to increased temperature and decreased salinity with large reductions in filtration rates occurring (Javanshir, 2001b). Thus infected animals may surface as a direct result of limited oxygen availability in the tissues (Javanshir, 2001a) rather than due to a parasite-derived dispersal strategy. There is an inverse relationship between parasite levels in the host and oxygen consumption rate; when more than 92% of body mass is made up of parasite, the host enters a lethal state leading to host death (Javanshir, 2001a).

Living organisms utilize metallothioneins (MT) in the metabolism of essential metals and in the detoxification of trace metals. The induction of these proteins has been used as a biological monitoring tool in the marine environment as a marker of exposure to heavy metal contamination (Mourgaud *et al.*, 2002). Baudrimont *et al.* (2006) compared MT concentration in parasitized and non-parasitized cockles during gametogenesis and after spawning. Spent cockles parasitized by *B. minimus* had MT levels that were higher than non-parasitized individuals. In contrast, parasitized cockles undergoing gametogenesis had lower MT levels than non-parasitized cockles. The authors suggested that parasites in the cockle, particularly those that castrate the host appear to modulate MT synthesis and infected animals were more likely to bioaccumulate metals (Baudrimont *et al.*, 2006; Baudrimont & de Montaudouin, 2007).

Curtuteria arguinae Desclaux, Russell-Pinto, de Montaudouin & Bachelet, 2006 (family Echinostomatidae) was described from cockles in France, and has been reported in Portugal and Morocco (Russell-Pinto *et al.*, 2006; Gam *et al.*, 2008). Although the parasite has been noted in cockles as small as 3 mm, significant infections do not occur until the cockle is larger than 14 mm (Desclaux *et al.*, 2006). In selected cockle cohorts it has been shown to lead to parasite-dependent mortality (Desclaux *et al.*, 2006).

The taxonomy of the digenean family Gymnophallidae has been the subject of much controversy with numerous authors attempting to resolve the convoluted taxonomic history (Cable, 1953; Stunkard & Uzmann, 1958; James, 1964; Pekkarinen & Ching, 1994; Ching, 1995; Bowers *et al.*, 1996; Scholz, 2002; Cremonte *et al.*, 2008). Scholz (2002) attempted to stabilize the taxonomy by synonymizing a number of genera. The genera proposed by Scholz (2002) include *Parvatrema* (= *Meiogymnophallus*), *Gymnophallus* (= *Paragymnophallus*), *Gymnophalloides* (= *Lacunovermis*) and *Pseudogymnophallus*. A fifth genus, *Bartolius*, was erected by Cremonte (2001) and only briefly mentioned in the review by Scholz (2002). Not all authors have agreed with the proposal of Scholz (2002) and have continued to use the genus name *Meiogymnophallus* for gymnophallids occurring in bivalves (Russell-Pinto *et al.*, 2006; Chai *et al.*, 2007; de Montaudouin *et al.*, 2009; Fermer *et al.*, 2010, 2011). The suppression of *Meiogymnophallus* as a junior synonym of *Parvatrema* requires reconsideration as it is apparent that not all members of the genus *Meiogymnophallus* are readily placed in the genus *Parvatrema* (Bartoli & Gibson, 2007). Indeed, all gymnophallids occurring in *Cerastoderma* appear to have characteristics of the genus *Gymnophallus* and thus we propose that until evidence is provided to the contrary, all gymnophallids occurring in cockles should be considered as *Gymnophallus* spp. The gymnophallid reported as *P. isostoma* Beloplo'skaja, 1966 in *C. glaucum* by Dolgikh (1968) requires redescription as Bartoli (1983) considered this to be conspecific with *G. rebecqui* Bartoli, 1983.

Mortalities of cockles in the northern Wadden Sea area were attributed to the presence of *Gymnophallus choledochus* Odhner, 1900 (family Gymnophallidae) (Figure 4E, F), which was confirmed by surveys of cockles that showed that 73% of surfaced cockles were infected with the parasites compared to only 7% of buried cockles (Thieltges, 2006). In addition, following experimental studies, only 23% of those cockles on the surface survived longer than 14 days. The parasite appears to be more common in edible cockles compared with lagoon cockles (Boyden, 1970; Culurgioni *et al.*, 2006; Figus *et al.*, 2006).

Gymnophallus (= *Meiogymnophallus*) *minutus* has been recorded on a number of occasions from cockle populations in Europe (Bowers & James, 1967). The parasite occurs enveloped by host tissue below the hinge area (Figure 5A) and stimulates the cockle to produce excessive ligament proteins, resulting in tissue folding around the parasite. Similar lesions have been reported in other bivalve species with a concomitant effect on survival (Campbell, 1985; Cremonte & Ituarte, 2003; Mladineo & Peharda, 2009; Addinoa *et al.*, 2010). Bowers *et al.* (1996) suggested that this interfered with the close fitting of the tooth into the wedge shaped cavity by the hinge leading to an incomplete closure of the shell valves. Infected animals were more likely to be found close to or on the surface of the sediment with the open shell gaping upwards. James *et al.* (1977) and Goater (1993) reported mass mortalities of cockles infected with *G. minutus* in the Burry Inlet and Exe estuary respectively. However, Fermer *et al.* (2010, 2011) suggest that there is no empirical evidence of an effect of the parasite on gaping, altered burrowing or direct mortality. The parasite is host to the microsporidian *Unikaryon legeri* (Figure 5B).

Four members of the genus *Himasthla* (family Echinostomatidae) occur as metacercaria in the foot and

mantle of cockles (Figure 5C). Three of these, *H. elongata* (Mehlis, 1831), *H. interrupta* Loos-Frank, 1967 and *H. continua* Loos-Frank, 1967 are considered to be native to *C. edule* and *C. glaucum* and are identifiable by the presence of 29 collar spines. The life cycle of a fourth species, *H. quissetensis* (Miller & Northup, 1926) with 31 collar spines was described from *Mya arenaria* Linnaeus, 1758 in North America (Stunkard, 1938) and has been reported in cockles in Europe (Bartoli & Gibson, 2007). de Montaudouin *et al.* (2005) consider that the parasite is a recent introduction from the USA into Europe, although a 'rare' *Himasthla* sp. with 31 collar spines which may be conspecific with *H. quissetensis* has been noted previously in the North Sea (Lauckner, 1971). The three native *Himasthla* spp. use either *Hydrobia ulvae* (Pennant, 1777) or *Littorina littorea* (Linnaeus, 1758) as first intermediate host whilst the non-native *H. quissetensis* has been recorded as cercaria in *Nassarius reticulatus* (Linnaeus, 1758) in Portugal (Russell-Pinto *et al.*, 2006). They are able to infect spat as well as recently settled cockles around 4 mm in size and infect cockles in their first summer (Jensen *et al.*, 1999; Wegeberg *et al.*, 1999; de Montaudouin *et al.*, 2005). Transmission of the parasites occurs following predation on cockles by migratory birds (de Montaudouin *et al.*, 1998).

It has been difficult to unequivocally link the presence of *Himasthla* spp. directly to mortalities, despite both field and experimental studies. Wegeberg & Jensen (1999) held cockles under hypoxic conditions for 30 hours. Survival of cockles infected with *H. elongata* was significantly reduced compared with non-infected hosts. In contrast however, under normal conditions there was no effect of parasites on survival. This was supported by the studies of Desclaux *et al.* (2004) who showed that whilst the parasites had some direct impact on host survival, being responsible for up to 46% of the mortality, it was the synergistic effect of environmental conditions coupled with the presence of the parasite that caused the majority of deaths. Cockles infected with more than 10 *H. quissetensis* metacercariae are more likely to be found on the surface compared with uninfected or cockles with lower numbers of metacercariae (Desclaux *et al.*, 2002) which may be due to a mechanical interruption of the cockles ability to burrow and increasing time to burrow by up to 20 times (Lauckner, 1984). As with other digeneans, *H. interrupta* can cause loss of flesh weight and body condition (Wegeberg & Jensen, 2003); marginal reductions in growth rates occur in animals infected with *Himasthla* spp. (Javanshir *et al.*, 2007). *Himasthla* spp. infections in the foot of cockles are considered to destroy muscle fibres as they migrate through the muscle layers either through mechanical pressure or through the release of cercarial enzymes as well as causing pressure atrophy and haemocyte accumulations once embedded in the host (Desclaux *et al.*, 2004).

Cockles infected with the digenean *Monorchis parvus* Loos, 1902 (family Monorchidae) (Figure 5D) are significantly smaller than healthy individuals, particularly in the early years (Sannia & James, 1978). However, it is considered to be relatively rare in the UK, being recorded sporadically in the Thames (at a prevalence of 1%) in 1975–1976, the north-east of England in three cockles (Lebour, 1912), Scotland (at a prevalence of 0.5%), and the south-east of England (at a prevalence of 0.15%). Boyden (1970) reported the parasite in 0.07% of *C. edule* and 0.12% of *C. glaucum*. Infected cockles that were not eaten by the final host died within 12 months of

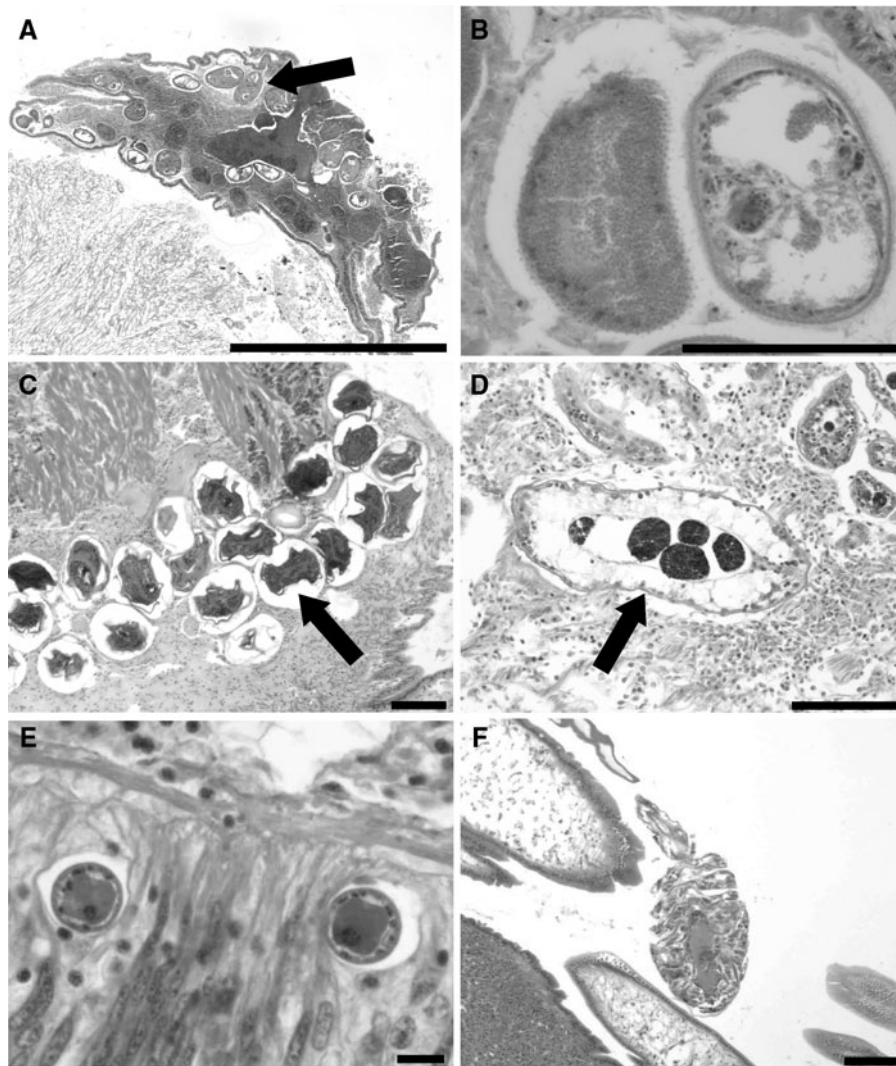


Fig. 5. Histopathology of infections in *Cerastoderma* spp.: (A) low power view of cockle infected with *Gymnophallus* (= *Meiogymnophallus*) *minutus* (arrow). Note also the presence of numerous dead digeneans within the sporocyst as a result of hyperparasitism by *Unikaryon legeri*; (B) histological section through two *G. minutus*. Individual on left shows heavy infection with the hyperparasite *U. legeri*. In addition, note the presence of small spines along body wall on peripheral edges of both specimens, a typical feature of the parasite; (C) metacercaria of *Himasthla* sp. in the mantle of cockle (arrow). Note moderate host reaction surrounding the parasites that occur within a pearl; (D) daughter sporocyst of *Monorchis parvus* (arrow) containing developing germinal cells which eventually develop into metacercaria; (E) cross-section through two unidentified nematodes embedded within the epithelium of intestine. Note the lack of host response to the nematodes; (F) *Herrmannella rostrata* on the gills of cockle. Scale bar for A = 1 mm; B, C, D, E and F = 100 μ m. Histological sections stained with haematoxylin and eosin (H&E).

being exposed to the parasite (Sannia & James, 1978). Jonsson & André (1992), following reports of a mass mortality of cockles in Sweden, examined animals from two localities. In addition to carrying out a histological study of these animals, the authors tested the burrowing capability of the cockles under experimental conditions. Significantly fewer infected individuals burrowed compared with their uninfected counterparts. Damage to the infected tissues was defined as 'serious' and many individuals had no remaining muscular tissue in the foot and few gametes were detected. Jonsson & André (1992) report that heavily infected cockles 'were slow to close the valves and gave off a putrid smell' and that cockles gaping on the surface were often attacked by the gastropod *N. reticulatus*. They concluded that the parasite, which uses sparids (*Diplodus* spp.) as a final host (Bartoli *et al.*, 2000), was responsible for the reported mortalities in Swedish coastal areas.

Psilostomum brevicolle (Linton, 1928) (family Psilostomidae) occurs in the visceral mass of *C. glaucum* and *C. edule* along the Atlantic coast of Europe with a more northerly distribution and an apparent absence in the Mediterranean Sea (de Montaudouin *et al.*, 2009; Derbali *et al.*, 2009). Prevalence is variable between sites with no significant difference in prevalence or intensity between buried and unburied cockles suggesting that it is not a mortality driver for cockles (Desclaux *et al.*, 2002). Infection of cockles takes place in autumn in animals greater than 19 mm in length (de Montaudouin *et al.*, 2000). No data exist on the pathology associated with this parasite or its impact on cockle hosts.

Renicola roscovita (Stunkard, 1932) (family Rencolidae) infect a number of bivalve species and has a preference for the palps of larger cockles (de Montaudouin *et al.*, 2000; Thieltges & Reise, 2006). Lauckner (1984) suggested that juvenile cockles were more likely to die as a result of

infection due to the preference of the parasite to encyst in the gills and visceral mass of smaller cockles. Cockles are infected in their first summer when around 5 mm in size with accumulation of parasites continuing through the life of the host (de Montaudouin *et al.*, 2000; Thieltges & Reise, 2007; Thieltges, 2008). Peak transmission occurs during the summer months and although maximum infectivity of cercariae occurs at 25°C, the optimum temperature for transmission is 20°C (Thieltges & Rick, 2006). Cockles originating from low intertidal areas of the shore line have higher levels of *R. roscovita* compared with cockles from other parts of the shoreline, reflecting the higher densities of the first intermediate host *H. ulvae* in this area (Thieltges, 2007).

The life cycle of *Diptherostomum brusinae* Stossich, 1888 (family Zoogonidae) was recently demonstrated by Pina *et al.* (2009b) using a molecular approach to link different life stages in each host. Sporocysts containing cercaria and encysted metacercaria occur within the gonads and digestive gland of *N. reticulatus*. Cercaria can encyst within the gastropod host for transmission direct to the fish host or can be released and infect *C. edule* where the metacercaria occur in the foot, mantle border and gills (Pina *et al.*, 2009b). Palombi (1930) and Bartoli & Gibson (2007) suggest that there is no second intermediate host and that transmission occurs directly from the gastropod to the fish hosts although Francisco *et al.* (2010a) have shown that *Mytilus galloprovincialis* Lamarck, 1819 can act as a second intermediate host for the parasite. Molecular primers for the ITS1 and for 18 rDNA are provided by Pina *et al.* (2009b) and Francisco *et al.* (2010a). No data exist on the impact of the parasite in cockles, although Francisco *et al.* (2010b) have shown that the parasite elicits a strong immune response consisting of haemocyte encapsulation in *M. galloprovincialis*.

Digenea of lesser concern that have not been shown to impact on the overall health of cockles include *Lepocreadium pegorchis* (Stossich, 1901) (family Lepocreadiidae), the freshwater digenean *Asymphylogora demeli* Markowski, 1935 (family Lissorchiidae) and *Paratimonia gobii* Prévôt & Bartoli, 1967 (family Monorchidae) (Reimer, 1973; Maillard, 1975a; Kesting *et al.*, 1996; Zander, 1998; Bartoli & Gibson, 2007; de Montaudouin *et al.*, 2009). Cercarial stages of the digenean *Parorchis acanthus* Nicoll, 1907 (family Philophthalmidae) encyst on a number of surfaces including the foot, mantle and shell of *C. edule* which erroneously led Lebour & Elmhirst (1922) to suggest that they may be intermediate hosts for this parasite.

PHYLUM PLATYHELMINTHES— CLASS CESTODA

Cestodes have a complex life cycle utilizing at least two hosts, usually an invertebrate and a vertebrate host (Gulyaev, 2008). In general, few bivalves have been reported as being hosts for cestodes (Maeno *et al.*, 2006; Aguirre-Macedo *et al.*, 2007; Kim & Powell, 2007; Park *et al.*, 2008; Holland & Wilson, 2009). de Montaudouin *et al.* (2000) reported the presence of an unidentified cestode (as a tentaculo-neoplercercoid) in the foot of *Cerastoderma edule* from Arcachon Bay, France at a prevalence of 0.4% (two animals infected), whilst Vaullegeard (1900) listed '*Cardium*' as a host for *Echinobothrium typus* van Beneden, 1849 (family Echinobothriidae). James *et al.* (1977)

recorded *Anatinella* (= *Monosaccanthus* = *Hymenolepis*) *brachycephala* (Creplin, 1829) cysticeroid larvae in the haemolymph of the digestive gland and foot of *C. edule* from the Burry Inlet, South Wales. No prevalence data or pathology information were provided. Final host for this cestode was recorded as the oystercatcher.

PHYLUM NEMATODA

Life cycles of parasitic nematodes are normally complex, with at least three hosts, including bivalves in a small number of cases. However, reports of nematodes in both *Cerastoderma edule* and *C. glaucum* are rare. Unidentified ectocommensal nematodes occur in the mantle cavity and gills of *C. edule* and *C. glaucum* in the Wadden Sea and Mediterranean Sea respectively and do not elicit a host response (Culurgioni *et al.*, 2006; Figus *et al.*, 2006; Thieltges *et al.*, 2006). Chao (2000), quoting a list of unpublished data from B. James, reported third stage larvae of *Porrocaecum pectinis* Cobb, 1930 in the digestive gland and gonads of cockles (Figure 5E). However, *P. pectinis* is a parasite of *Argopecten gibbus* (Linnaeus, 1758) from the south-eastern USA (Minchin, 2003) and thus its report in cockles must be considered dubious.

PHYLUM ARTHROPODA

The copepod *Herrmannella rostrata* Canu, 1891 occurs in the mantle cavity and gills (Figure 5F) of *Cerastoderma edule* from the British Isles, France, Spain and The Netherlands (Atkins, 1934; Stock, 1993; Carballal *et al.*, 2001; Faasse, 2003). Typically the parasite undergoes six naupliar stages, five copepodid stages and a single adult stage where the sexes are separate (Costanzo & Calafiore, 1985); no pathology or detrimental impact has been noted for this parasite.

The intestine dwelling copepod *Mytilicola intestinalis* Steuer, 1902, occurs in a number of bivalve species, notably *Mytilus* spp. (Aguirre-Macedo & Kennedy, 1999; Buck *et al.*, 2005). Under low levels of infection the parasite is considered benign; numbers of more than 3 individuals per infected mussel appear to be detrimental to the host (Gee & Davey, 1986; Watermann *et al.*, 2008). Local metaplasia of the intestinal lumen of a single cockle infected with a *Mytilicola* sp. in Galicia was noted by Carballal *et al.* (2001). Overall prevalence of the parasite in the samples from 3 sites in Galicia, Spain was only 4%. Similarly low prevalence values were obtained by de Montaudouin *et al.* (2000) in Arcachon Bay, France who showed that the parasite did not infect individuals smaller than 9 mm. Its presence in the Burry Inlet in South Wales was noted by James *et al.* (1977); no data on prevalence, intensity or impact were provided by these authors.

Pea crabs live commensally in a range of marine invertebrates, including bivalve molluscs, with the common *Pinnotheres pisum* (Linnaeus, 1767) infecting a number of bivalve species in Europe (Becker & Türkay, 2010). Pea crabs infecting other hosts can lead to reductions in growth and condition factor and impact gonadal development as well as damaging the gills (Kruczynski, 1972; Bierbaum & Ferson, 1986; O'Beirn & Walker, 1999; Mercado-Silva, 2005; Sun *et al.*, 2006). However, no studies have been carried out

on the impact of *P. pisum* on cockle growth or survival although it has been noted in the mantle cavity of up to 70% of *C. edule* from Morocco and at an unknown prevalence in the Burry Inlet (James *et al.*, 1977; Gam *et al.*, 2008). The pea crab, *Afropinnotheres monodi* Manning, 1993, originally described from Moroccan waters, has now been found in three native bivalve species, including *C. glaucum*, in the Gulf of Cadiz (Portugal) (Subida *et al.*, 2011).

PHYLUM NEMERTEA

The entocommensal nemertean *Malacobdella grossa* (Müller, 1776) is associated with a number of bivalves around the coastlines of Europe and the Pacific and Atlantic coasts of the Americas (Gibson, 1967). In the bivalve host, the nemertean either predated on small crustaceans entering the mantle cavity or those living commensally with its bivalve host (Gibson & Jennings, 1969). *Malacobdella grossa* was noted in the mantle cavity of *Cerastoderma edule* from the Shetland Islands by Jones *et al.* (1979). Prevalence was close to 100% at some sites and cockles less than 15 mm were uninfected (Jones *et al.*, 1979). The relationship between the haplosporidian *Haplosporidium malacobdellae* Jennings & Gibson, 1968 in *M. grossa* and those occurring in cockles are unknown (McDermott, 2006). No further information on the impact of *M. grossa* on cockle health was noted and it has not been recorded since.

CONCLUSIONS AND FUTURE DIRECTIONS

This review has covered all the disease conditions, parasites and commensals of cockles, and considered the effect of these on both individual and population health. It has been clear that in a number of areas there are large gaps in our knowledge that require further studies. In particular, there has been a lack of taxonomic rigour applied to many studies on parasites and diseases and as a result, there has been a number of poorly described species and erroneous host records. The limited data on some parasite life cycles, in particular haplosporidians, *Marteilia* sp. and Digenea, should be addressed using a combination of molecular and experimental approaches and the pathological impact of infections should be considered through the use of histopathology and field and experimental studies. The role of plankton in the dissemination of selected cockle pathogens should be examined as this constitutes a major component of cockle diets. Use of both *in vitro* and *in vivo* models to assess impact of infections should be considered. These data along with life history information will be useful in determining impact of these parasites at an individual and population level and minimize risk of transfer of non-native parasites between sites. A clear understanding of the species and hosts involved along with the impact of these parasites will ensure that biologically relevant decisions are made in managing any cockle fishery. No data exist on infections of larval cockles or on the impact of these on survival although some studies have considered digenean infections of recently settled spat; this gap needs to be addressed.

ACKNOWLEDGEMENT

The authors thank the Welsh Government for providing financial support for the production of this review.

REFERENCES

- Addinoa M., Lomovaskya B.J., Cremonte F. and Iribarne O.** (2010) Infection by gymnophallid metacercariae enhances predation mortality of SW Atlantic stout razor clam *Tagelus plebeius*. *Journal of Sea Research* 63, 102–107.
- Aguirre-Macedo M.L. and Kennedy C.R.** (1999) Diversity of metazoan parasites of the introduced oyster species *Crassostrea gigas* in the Exe Estuary. *Journal of the Marine Biological Association of the United Kingdom* 79, 57–63.
- Aguirre-Macedo M.L., Sima-Alvarez R.A., Román-Magaña M.K. and Guemez-Ricalde J.I.** (2007) Parasite survey of the eastern oyster *Crassostrea virginica* in coastal lagoons of the southern Gulf of Mexico. *Journal of Aquatic Animal Health* 19, 270–279.
- Anderson T.J., Hine P.M. and Lester R.J.G.** (1995) A *Steinhausia*-like infection in the ovocytes of Sydney rock oysters *Saccostrea commercialis*. *Diseases of Aquatic Organisms* 22, 143–146.
- Atkins D.** (1933) *Rhopalura granosa* sp. nov., an orthonectid parasite of a lamellibranch *Heteranomia squamula* L., with a note on its swimming behaviour. *Journal of the Marine Biological Association of the United Kingdom* 19, 233–252.
- Atkins D.** (1934) Two parasites of the common cockle *Cardium edule*: a rhabdocoele *Paravortex cardii* Hallez and a copepod *Paranthesius rostratus*. *Journal of the Marine Biological Association of the United Kingdom* 19, 669–676.
- Atkins D.** (1954) Further notes on a marine member of the Saprolegniaceae, *Leptolegnia marina* n. sp., infecting certain invertebrates. *Journal of the Marine Biological Association of the United Kingdom* 33, 613–625.
- Audemard C., Le Roux F., Barnaud A., Collins C., Sautour B., Sauriau P.-G., de Montaudouin X., Coustau C., Combes C. and Berthe F.** (2002) Needle in a haystack: involvement of the copepod *Paracartia grani* in the life-cycle of the oyster pathogen *Marteilia refringens*. *Parasitology* 124, 315–323.
- Auffret M. and Poder M.** (1987) Pathology of the main bivalve mollusc species from oyster rearing areas in Brittany (France). *Aquaculture* 67, 255–257.
- Azevedo C.** (1993) Occurrence of an unusual branchial mycoplasma-like infection in cockle *Cerastoderma edule* (Mollusca, Bivalvia). *Diseases of Aquatic Organisms* 16, 55–59.
- Azevedo C.** (1997) Some observations on an amoeba, destructive agent of the gills of *Cerastoderma edule* (Mollusca, Bivalvia). *Diseases of Aquatic Organisms* 30, 223–225.
- Azevedo C. and Cachola R.** (1992) Fine structure of the apicomplexa oocyst of *Nematopsis* sp. of two marine bivalve mollusks. *Diseases of Aquatic Organisms* 14, 69–73.
- Azevedo C. and Canning E.U.** (1987) Ultrastructure of a microsporidian hyperparasite, *Unikaryon legeri* (Microsporidia), of trematode larvae. *Journal of Parasitology* 73, 214–223.
- Azevedo C., Conchas R.F. and Montes J.** (2003) Description of *Haplosporidium edule* n. sp. (Phylum Haplosporidia), a parasite of *Cerastoderma edule* (Mollusca, Bivalvia) with complex spore ornamentation. *European Journal of Protistology* 39, 161–167.

- Azevedo C. and Villalba A.** (1991) Extracellular giant rickettsiae associated with bacteria in the gill of *Crassostrea gigas* (Mollusca, Bivalvia). *Journal of Invertebrate Pathology* 58, 75–81.
- Babarro J.M.F. and de Zwaan A.** (2001) Factors involved in the (near) anoxic survival time of *Cerastoderma edule*: associated bacteria vs. endogenous fuel. *Comparative Biochemistry and Physiology—C: Toxicology and Pharmacology* 128, 325–337.
- Babarro J.M.F. and de Zwaan A.** (2008) Anaerobic survival potential of four bivalves from different habitats. A comparative survey. *Comparative Biochemistry and Physiology—A: Molecular and Integrative Physiology* 151, 108–113.
- Barber B.J.** (2004) Neoplastic diseases of commercially important marine bivalves. *Aquatic Living Resources* 17, 449–466.
- Bartoli P.** (1983) *Gymnophallus rebecqui* n. sp. (syn. *Parvatrema* sp. 1, J. Rebecq, 1964) (Digenea: Gymnophallidae), an intestinal parasite of ducks from Camargue (France). *Annales de Parasitologie Humaine et Comparée* 58, 211–225.
- Bartoli P. and Gibson D.I.** (2007) Synopsis of the life cycles of Digenea (Platyhelminthes) from lagoons of the northern coast of the western Mediterranean. *Journal of Natural History* 41, 1553–1570.
- Bartoli P., Jousson O. and Russell-Pinto F.** (2000) The life cycle of *Monorchis parvus* (Digenea: Monorchidae) demonstrated by developmental and molecular data. *Journal of Parasitology* 86, 479–489.
- Baudrimont M. and de Montaudouin X.** (2007) Evidence of an altered protective effect of metallothioneins after cadmium exposure in the digenean parasite-infected cockle (*Cerastoderma edule*). *Parasitology* 134, 237–245.
- Baudrimont M., de Montaudouin X. and Palvadeau A.** (2006) Impact of digenean parasite infection on metallothionein synthesis by the cockle (*Cerastoderma edule*): a multivariate field monitoring. *Marine Pollution Bulletin* 52, 494–502.
- Becker C. and Türkay M.** (2010) Taxonomy and morphology of European pea crabs (Crustacea: Brachyura: Pinnotheridae). *Journal of Natural History* 44, 1555–1575.
- Belofastova I.P.** (1996) Gregarines of the genus *Nematopsis* (Eugregarinida: Porosporidae), parasites of the Black Sea molluscs. *Parazitologiya* 30, 159–173.
- Belofastova I.P. and Dmitrieva E.V.** (1999) The turbellarians of genus *Paravortex* (Rhabdozoa: Graffillidae)—parasites of the Black Sea bivalves. *Ecologiya Morya* 48, 76–78.
- Bierbaum R.M. and Ferson S.** (1986) Do symbiotic pea crabs decrease growth rate in mussels? *Biological Bulletin. Marine Biological Laboratory, Woods Hole* 170, 51–61.
- Blanchet H., Raymond N., de Montaudouin X., Capdepuy M. and Bachelet G.** (2003) Effects of digenean trematodes and heterotrophic bacteria on mortality and burying capability of the common cockle *Cerastoderma edule* (L.). *Journal of Experimental Marine Biology and Ecology* 293, 89–105.
- Bowers E.A.** (1969) *Cercaria bucephalopsis haimeana* (Lacaze-Duthiers, 1854) (Digenea: Bucephalidae) in the cockle, *Cardium edule* L. in South Wales. *Journal of Natural History* 3, 409–422.
- Bowers E.A., Bartoli P., Russell-Pinto F. and James B.L.** (1996) The metacercariae of sibling species of *Meiogymnophallus*, including *M. rebequi* comb. nov. (Digenea: Gymnophallidae), and their effects on closely related *Cerastoderma* host species (Mollusca: Bivalvia). *Parasitology Research* 82, 505–510.
- Bowers E.A. and James B.L.** (1967) Studies on the morphology, ecology and life-cycle of *Meiogymnophallus minutus* (Cobbold, 1859) comb. nov. (Trematoda: Gymnophallidae). *Parasitology* 57, 281–300.
- Bowmer T., Jenner H.A., Foekema E. and Van der Meer M.** (1994) The detection of chronic biological effects in the marine intertidal bivalve *Cerastoderma edule*, in model ecosystem studies with pulverised fuel ash: reproduction and histopathology. *Environmental Pollution* 85, 191–204.
- Boyden C.R.** (1970) *Comparative studies of Cerastoderma edule (L.) and Cerastoderma glaucum (Poirlet)*. PhD thesis. University of London, United Kingdom.
- Boyden C.R.** (1971) A comparative study of the reproductive cycles of the cockles *Cerastoderma edule* and *C. glaucum*. *Journal of the Marine Biological Association of the United Kingdom* 51, 605–622.
- Brusa F., Ponce de Leon R. and Damborenea C.** (2006) A new *Paravortex* (Platyhelminthes, Dalyellioida) endoparasite of *Mesodesma mactroides* (Bivalvia, Mesodesmatidae) from Uruguay. *Parasitology Research* 99, 566–571.
- Buck B.H., Thieltges D.W., Walter U., Nehls G. and Rosenthal H.** (2005) Inshore–offshore comparison of parasite infestation in *Mytilus edulis*: implications for open ocean aquaculture. *Journal of Applied Ichthyology* 21, 107–113.
- Burreson E.M. and Ford S.E.** (2004) A review of recent information on the Haplosporidia, with special reference to *Haplosporidium nelsoni* (MSX disease). *Aquatic Living Resources* 17, 499–517.
- Cable R.M.** (1953) The life cycle of *Parvatrema borinquena* gen. et sp. nov. (Trematoda: Digenea) and the systematic position of the subfamily Gymnophallinae. *Journal of Parasitology* 39, 408–421.
- Cajaraville M.P. and Angulo E.** (1991) *Chlamydia*-like organisms in digestive and duct cells of mussels from the Basque coast. *Journal of Invertebrate Pathology* 58, 381–386.
- Campbell D.** (1985) The life cycle of *Gymnophallus rebecqui* (Digenea: Gymnophallidae) and the response of the bivalve *Abra tenuis* to its metacercariae. *Journal of the Marine Biological Association of the United Kingdom* 65, 589–601.
- Canning E.U. and Nicholas J.P.** (1974) Light and electron microscope observations on *Unikaryon legeri* (Microsporidia, Nosematidae), a parasite of the metacercaria of *Meiogymnophallus minutus* in *Cardium edule*. *Journal of Invertebrate Pathology* 23, 92–100.
- Carballal M.J., Diaz S. and Villalba A.** (2005) *Urosporidium* sp. hyperparasite of the turbellarian *Paravortex cardii* in the cockle *Cerastoderma edule*. *Journal of Invertebrate Pathology* 90, 104–107.
- Carballal M.J., Iglesias D., Santamarina J., Ferro-Soto B. and Villalba A.** (2001) Parasites and pathologic conditions of the cockle *Cerastoderma edule* populations of the coast of Galicia (NW Spain). *Journal of Invertebrate Pathology* 78, 87–97.
- Carballal M.J., Villalba A., Iglesias D. and Hine P.M.** (2003) Virus-like particles associated with large foci of heavy hemocytic infiltration in cockles *Cerastoderma edule* from Galicia (NW Spain). *Journal of Invertebrate Pathology* 84, 234–237.
- Carrasco N., Arzul I., Chollet B., Robert M., Joly J.P., Furones M.D. and Berthe F.C.J.** (2008) Comparative experimental infection of the copepod *Paracartia grani* with *Marteilia refringens* and *Marteilia maurini*. *Journal of Fish Diseases* 31, 497–504.
- Carrasco N., Roque A., Andree K.B., Rodgers C., Lacuesta B. and Furones M.D.** (2011) A *Marteilia* parasite and digestive epithelial virosis lesions observed during a common edible cockle *Cerastoderma edule* mortality event in the Spanish Mediterranean coast. *Aquaculture* 321, 197–202.
- Carrasco N., Andree K.B., Lacuesta B., Roque A., Rodgers C. and Furones M.D.** (2012) Molecular characterization of the *Marteilia* parasite infecting the common edible cockle *Cerastoderma edule* in the Spanish Mediterranean coast: a new *Marteilia* species affecting bivalves in Europe? *Aquaculture* 324–325, 20–26.

- Chai J.Y., Han E.T., Choi D., Seo M., Kim J.L., Guk S.M., Shin E.H. and Lee S.H. (2007) A new gymnohallid trematode from the intestine of mice infected with metacercariae from the razor clam *Sinonovacula constricta*. *Journal of Parasitology* 93, 132–137.
- Chao P.-P. (2000) *Taxonomic studies on the shells, allozymes and parasites of European cockles in the Cerastoderma edule (L.) and Cerastoderma glaucum (Bruguère) species complex*. PhD thesis. University of Wales, Swansea, United Kingdom.
- Cheng T.C. and Burton R.W. (1965) Relationships between *Bucephalus* sp. and *Crassostrea virginica*: histopathology and sites of infection. *Chesapeake Science* 6, 3–16.
- Ching H.L. (1995) Evaluation of characters of the digenean family Gymnohallidae Morozov, 1955. *Canadian Journal of Fisheries and Aquatic Sciences* 52, 78–83.
- Clopton R.E. (2002) Phylum Apicomplexa Levine, 1970: Order Eugregarinorida Léger, 1900. In Lee J.J., Leedale G., Patterson D. and Bradbury P.C. (eds) *Illustrated guide to the protozoa*. Lawrence, KS: Society of Protozoologists, pp. 205–288.
- Cole H.A. (1956) Benthos and the shellfish of commerce. In Graham M. (ed.) *Sea fisheries. Their investigation in the United Kingdom*. London: Edward Arnold (Publishers) Ltd, pp. 139–206.
- Collins C.M. and Mulcahy M.F. (2003) Cell-free transmission of a haemic neoplasm in the cockle *Cerastoderma edule*. *Diseases of Aquatic Organisms* 54, 61–67.
- Comps M., Grizel H., Tige G. and Duthoit J.-L. (1975) Parasites nouveaux de la glande digestive des mollusques marins *Mytilus edulis* L. et *Cardium edule* L. *Comptes Rendus Académie des Sciences de Paris (Séries D)* 281, 179–181.
- Comtet T., Garcia C., Le Coguc Y. and Joly J.-P. (2003) Infection of the cockle *Cerastoderma edule* in the Baie des Veys (France) by the microsporidian *Steinhausia* sp. *Diseases of Aquatic Organisms* 57, 135–139.
- Costanzo G. and Calafiore N. (1985) Larval development of *Herrmannella rostrata* Canu, 1891 (Copepoda, Poecilostomatoida, Sabelliphilidae) of the Lake Faro (Messina) reared in the laboratory. *Memorie di Biologia Marina e di Oceanografia* 15, 141–154.
- Cremonte F. (2001) *Bartolius pierrei* n. g., n. sp. (Digenea: Gymnohallidae) from the Peninsula Valdes, Argentina. *Systematic Parasitology* 49, 139–147.
- Cremonte F. and Ituarte C. (2003) Pathologies elicited by the gymnohallid metacercariae of *Bartolius pierrei* in the clam *Darina solenoides*. *Journal of the Marine Biological Association of the United Kingdom* 83, 311–318.
- Cremonte F., Vázquez N. and Ituarte C. (2008) The development of *Gymnohallus australis* Szidat, 1962 (Digenea: Gymnohallidae) from the Patagonian coast (Argentina) from metacercaria to adult, with an amended diagnosis of *Gymnohallus* Odhner, 1905. *Systematic Parasitology* 69, 23–31.
- Culurgioni J., D'Amico V., De Murtas R., Trotti G.C. and Figus V. (2006) Parasitological monitoring of commercial native bivalves from St. Gilla lagoon (Sardinia, South Western Mediterranean). *Ittiopatologia* 3, 243–252.
- de Montaudouin X., Jensen K.T., Desclaux C., Wegeberg A.M. and Sajus M.C. (2005) Effect of intermediate host size (*Cerastoderma edule*) on infectivity of cercariae of *Himasthla quissetensis* (Echinostomatidae: Trematoda). *Journal of the Marine Biological Association of the United Kingdom* 85, 809–812.
- de Montaudouin X., Kisielewski I., Bachelet G. and Desclaux C. (2000) A census of macroparasites in an intertidal bivalve community, Arcachon Bay, France. *Oceanologica Acta* 23, 453–468.
- de Montaudouin X., Thieltges D.W., Gam M., Krakau M., Pina S., Bazairi H., Dabouineau L., Russell-Pinto F. and Jensen K.T. (2009) Digenean trematode species in the cockle *Cerastoderma edule*: identification key and distribution along the north-eastern Atlantic shoreline. *Journal of the Marine Biological Association of the United Kingdom* 89, 543–556.
- de Montaudouin X., Wegeberg A.M., Jensen K.T. and Sauriau P.G. (1998) Infection characteristics of *Himasthla elongata* cercariae in cockles as a function of water current. *Diseases of Aquatic Organisms* 34, 63–70.
- de Zwaan A., Babarro J.M.F., Monari M. and Cattani O. (2002) Anoxic survival potential of bivalves: (arte)facts. *Comparative Biochemistry and Physiology—A: Molecular and Integrative Physiology* 131, 615–624.
- Deltreil J.-P. and His E. (1970) Sur la présence d'une cercaire de trématode chez *Cardium edule* L. dans le bassin d'Arcachon. *Revue des Travaux de l'Institut des Pêches Maritimes* 34, 225–232.
- Derbali A., Jarboui O. and Ghorbel M. (2009) Reproductive biology of the cockle *Cerastoderma glaucum* (Mollusca: Bivalvia) from the north coast of Sfax (Gulf of Gabes, Tunisia). *Ciencias Marinas* 35, 141–152.
- Desclaux C., de Montaudouin X. and Bachelet G. (2002) Cockle emergence at the sediment surface: 'favourization' mechanism by digenean parasites? *Diseases of Aquatic Organisms* 52, 137–149.
- Desclaux C., de Montaudouin X. and Bachelet G. (2004) Cockle *Cerastoderma edule* population mortality: role of the digenean parasite *Himasthla quissetensis*. *Marine Ecology Progress Series* 279, 141–150.
- Desclaux C., Russell-Pinto F., de Montaudouin X. and Bachelet G. (2006) First record and description of metacercariae of *Curtuteria arguiniae* n. sp. (Digenea: Echinostomatidae), parasite of cockles *Cerastoderma edule* (Mollusca: Bivalvia) in Arcachon Bay, France. *Journal of Parasitology* 92, 578–587.
- Díaz S., Cao A., Villalba A. and Carballal M.J. (2010) Expression of mutant protein p53 and Hsp70 and Hsp90 chaperones in cockles *Cerastoderma edule* affected by neoplasia. *Diseases of Aquatic Organisms* 90, 219–226.
- Dolgikh A.V. (1968) The lifecycle of *Parvatrema isostoma* Belopol'skaja, 1966 (Trematoda, Gymnohallidae). *Doklady Akademii Nauk SSSR* 183, 1229–1231.
- Dubois S.Y., Savoye N., Sauriau P.G., Billy I., Martinez P. and de Montaudouin X. (2009) Digenean trematodes–marine mollusc relationships: a stable isotope study. *Diseases of Aquatic Organisms* 84, 65–77.
- Ducrottoy J.P., Rybarczyk H., Souprayan J., Bachelet G., Beukema J.J., Desprez M., Dörjes J., Essink K., Guillou J., Michaelis H., Sylvand B., Wilson J.G., Elkaïm B. and Ibanez F. (1989) A comparison of the population dynamics of the cockle (*Cerastoderma edule*, L.) in north-western Europe. *Proceedings of the Estuarine and Coastal Sciences Association Symposium* 19, 173–184.
- Engelsma M.Y., Roozenburg I., Voorbergen-Laarman M., Van den Brink A., Troost K., Ysebaert T., Bateman K. and Longshaw M. (2011) Digenean trematodes and haplosporidian protozoans associated with summer mortality of cockles *Cerastoderma edule* in the Oosterschelde, The Netherlands. In *European Association of Fish Pathologists Conference, Split, Croatia, 14–18 September 2011* (Abstract).
- Faasse M.A. (2003) Copepods associated with marine invertebrates in the Netherlands (Crustacea: Copepoda). *Nederlandse Faunistische Mededelingen* 19, 79–86.
- Faliex E. and Morand S. (1994) Population dynamics of the metacercarial stage of the bucephalid trematode, *Labratrema minimus* (Stossich, 1887) from Salses-Leucate lagoon (France) during cercarial shedding period. *Journal of Helminthology* 68, 35–40.

- Faliex E., Pagès J.R. and Combes C.** (2003) Circulation du trématode *Labratrema minimus* dans un écosystème lagunaire: stratégie de retour à l'hôte définitif. In Combes C. and Jourdane J. (eds) *Taxonomy, ecology and evolution of metazoan parasites*. Perpignan, France: Presses Universitaires de Perpignan, pp. 321–345.
- Feist S.W., Hine P.M., Bateman K.S., Stentiford G.D. and Longshaw M.** (2009) *Paramarteilia canceri* sp. n. (Cercozoa) in the European edible crab (*Cancer pagurus*) with a proposal for the revision of the order Paramyxida Chatton, 1911. *Folia Parasitologica* 56, 73–85.
- Fenchel T.** (1965) Ciliates from Scandinavian molluscs. *Ophelia* 2, 71–174.
- Fermer J., Culloty S.C., Kelly T.C. and O'Riordan R.M.** (2009) Intrapopulation distribution of *Meiogygnophallus minutus* (Digenea, Gymnophallidae) infections in its first and second intermediate host. *Parasitology Research* 105, 1231–1238.
- Fermer J., Culloty S.C., Kelly T.C. and O'Riordan R.M.** (2010) Temporal variation of *Meiogygnophallus minutus* infections in the first and second intermediate host. *Journal of Helminthology* 84, 362–368.
- Fermer J., Culloty S.C., Kelly T.C. and O'Riordan R.M.** (2011) Manipulation of *Cerastoderma edule* burrowing ability by *Meiogygnophallus minutus* metacercariae? *Journal of the Marine Biological Association of the United Kingdom* 91, 907–911.
- Figus V., Culurgioni J., De Murtas R. and Trotti G.C.** (2006) Parasites of *Cerastoderma glaucum* (Poiret, 1879) (Bivalvia: Cardiidae) from St. Gilla lagoon, Southern Sardinia. *Ittiopatologia* 3, 69–74.
- Fischer W.M. and Palmer J.D.** (2005) Evidence from small-subunit ribosomal RNA sequences for a fungal origin of Microsporidia. *Molecular Phylogenetics and Evolution* 36, 606–622.
- Ford S.E., Stokes N.A., Burrenson E.M., Scarpa E., Carnegie R.B., Kraeuter J.N. and Bushek D.** (2009) *Minchinia mercenariae* n. sp. (Haplosporidia) in the hard clam *Mercenaria mercenaria*: implications of a rare parasite in a commercially important host. *Journal of Eukaryotic Microbiology* 56, 542–551.
- Francisco C.J., Almeida A., Castro A.M., Pina S., Russell-Pinto F., Rodrigues P. and Santos M.J.** (2010a) Morphological and molecular analysis of metacercariae of *Diphtherostomum brusinae* (Stossich, 1888) Stossich, 1903 from a new bivalve host *Mytilus galloprovincialis*. *Journal of Helminthology* 85, 179–184.
- Francisco C.J., Hermida M.A. and Santos M.J.** (2010b) Parasites and symbionts from *Mytilus galloprovincialis* (Lamarck, 1819) (Bivalves: Mytilidae) of the Aveiro estuary Portugal. *Journal of Parasitology* 96, 200–205.
- Gam M., Bazaïri H., Jensen K.T. and de Montaudouin X.** (2008) Metazoan parasites in an intermediate host population near its southern border: the common cockle (*Cerastoderma edule*) and its trematodes in a Moroccan coastal lagoon (Merja Zerga). *Journal of the Marine Biological Association of the United Kingdom* 88, 357–364.
- Gee J.M. and Davey J.T.** (1986) Experimental studies on the infestation of *Mytilus edulis* (L.) by *Mytilicola intestinalis* Steuer (Copepoda, Cyclopoida). *Journal du Conseil International pour l'Exploration de la Mer* 42, 265–271.
- Ghimire T.J.** (2010) Redescription of genera of Family Eimeriidae Minchin, 1903. *International Journal for Life Sciences* 4, 26–47.
- Gibson R.** (1967) Occurrence of the entocommensal rhynchocoelan, *Malacobdella grossa*, in the oval piddock, *Zirfaea crispata*, on the Yorkshire coast. *Journal of the Marine Biological Association of the United Kingdom* 47, 301–317.
- Gibson R. and Jennings J.B.** (1969) Observations on the diet, feeding mechanisms, digestion and food reserves of the entocommensal rhynchocoelan *Malacobdella grossa*. *Journal of the Marine Biological Association of the United Kingdom* 49, 17–32.
- Gill E.E. and Fast N.M.** (2006) Assessing the microsporidia–fungi relationship: combined phylogenetic analysis of eight genes. *Gene* 375, 103–109.
- Goater C.P.** (1993) Population biology of *Meiogygnophallus minutus* (Trematoda: Gymnophallidae) in cockles *Cerastoderma edule* from the Exe estuary, England. *Journal of the Marine Biological Association of the United Kingdom* 73, 163–177.
- Gulyaev V.D.** (2008) Evolution of cestode life cycles. *Zoologičeskij Zhurnal* 87, 1411–1419.
- Hancock D.A.** (1970) The role of predators and parasites in a fishery for the mollusc *Cardium edule* L. In den Boer P.J. and Gradwell G.R. (eds) *Proceedings of the Advanced Study Institute on 'Dynamics of Numbers in Populations'*, pp. 419–439.
- Hancock D.A. and Urquhart A.E.** (1965) The determination of natural mortality and its causes in an exploited population of cockles (*Cardium edule* L.). *Fishery Investigations* 24, 1–40.
- Hirt R.P., Logsdon J.M., Healy B., Dorey M.W., Doolittle W.F. and Embley T.M.** (1999) Microsporidia are related to fungi: evidence from the largest subunit of RNA polymerase II and other proteins. *Proceedings of the National Academy of Sciences of the United States of America* 96, 580–585.
- Holland N.D. and Wilson N.G.** (2009) Molecular identification of larvae of a tetraphyllidean tapeworm (Platyhelminthes: Eucestoda) in a razor clam as an alternative intermediate host in the life cycle of *Acanthobothrium brevissimum*. *Journal of Parasitology* 95, 1215–1217.
- Hopkins S.H.** (1954) The American species of trematode confused with *Bucephalus (bucephalopsis) haimeanus*. *Parasitology* 44, 353–370.
- Horn M.** (2008) Chlamydiae as symbionts in eukaryotes. *Annual Review of Microbiology* 62, 113–131.
- Huet L.** (1888) Note sur une parasite nouveau du *Cardium edule*. *Bulletin de la Société Linnéenne de Normandie* 4, 149–152.
- James B.L.** (1964) The lifecycle of *Parvatrema homoeotectum* sp. nov. (Trematoda: Digenea) and a review of the family Gymnophallidae Morozov, 1955. *Parasitology* 54, 1–41.
- James B.L. and Bowers E.A.** (1967a) The effects of parasitism by the daughter sporocysts of *Cercaria bucephalopsis haimeana* Lacaze-Duthiers, 1854, on the digestive tubules of the cockle, *Cardium edule* L. *Parasitology* 57, 67–77.
- James B.L. and Bowers E.A.** (1967b) Histochemical observations on the occurrence of carbohydrates, lipids and enzymes in the daughter sporocyst of *Cercaria bucephalopsis haimeana* Lacaze-Duthiers, 1854 (Digenea: Bucephalidae). *Parasitology* 57, 79–86.
- James B.L., Bowers E.A. and Richards J.G.** (1966) The ultrastructure of the daughter sporocyst of *Cercaria bucephalopsis haimeana* Lacaze-Duthiers, 1854 from the edible cockle, *Cardium edule* L. *Parasitology* 56, 753–762.
- James B.L., Sannia A. and Bowers E.A.** (1977) Parasites of birds and shellfish. Problems of a small estuary. In Nelson-Smith A. and Bridges E.M. (eds) *Proceedings of the Symposium on the Burry Inlet (South Wales) held at the University College of Swansea*, pp. 1–16.
- Javanshir A.** (2001a) Influence of infestation by *Labratrema minimus* (Bucephalidae: Digenea) on oxygen consumption of edible cockle *Cerastoderma edule* (Mollusc: Bivalvia) in laboratory conditions. *Iranian Journal of Fisheries Science* 3, 39–54.
- Javanshir A.** (2001b) Influence of *Labratrema minutus* (Trematoda: Digenea) on filtration rate performance of edible cockle *Cerastoderma edule* in the extreme temperature and salinity conditions (an *in vitro* experiment). *Iranian Journal of Fisheries Science* 3, 73–94.

- Javanshir A., Seyfabadi S.J., Bachelet G. and Feghhi J. (2007) Impact of two parasitic trematodes, *Meiognymphallus minutus* and *Himasthla* spp., on the growth of cockle, *Cerastoderma edule*. *Iranian Journal of Fisheries Science* 6, 33–58.
- Jensen K.T., Castro N.F. and Bachelet G. (1999) Infectivity of *Himasthla* spp. (Trematoda) in cockle (*Cerastoderma edule*) spat. *Journal of the Marine Biological Association of the United Kingdom* 79, 265–271.
- Jones A.M., Jones Y.M. and James J.L. (1979) The incidence of the nemertine *Malacobdella grossa* in the bivalve *Cerastoderma edule* in Shetland. *Journal of the Marine Biological Association of the United Kingdom* 59, 373–375.
- Jonsson P.R. and André C. (1992) Mass-mortality of the bivalve *Cerastoderma edule* (Linnaeus) on the Swedish west coast caused by infestation with the digenean trematode *Cercaria cerastodermae* I. *Ophelia* 36, 151–157.
- Kesting V., Gollasch S. and Zander C. (1996) Parasite communities of the Schlei Fjord (Baltic coast of northern Germany). *Helgoland Marine Research* 50, 477–496.
- Kim Y. and Powell E.N. (2007) Distribution of parasites and pathologies in sentinel bivalves: NOAA Status and Trends 'Mussel Watch' Program. *Journal of Shellfish Research* 26, 1115–1151.
- Kniskern V.B. (1952) Studies on the trematode Family Bucephalidae Poche, 1907: Part I. A systematic review of the Family Bucephalidae. *Transactions of the American Microscopical Society* 71, 253–266.
- Kruczynski W.L. (1972) The effect of the pea crab, *Pinnotheres maculatus* Say, on growth of the bay scallop, *Argopecten irradians concentricus* (Say). *Chesapeake Science* 13, 218–220.
- Lacaze-Duthiers F.J.H. (1854) Mémoire sur le bucéphale haime (*Bucephalus haimeanus*), helminthe parasite des huitres et des bucardes. *Annales des Sciences Naturelles Paris (Zoologie)* 4, 294–302.
- Landsberg J.H. (1996) Neoplasia and biotoxins in bivalves: is there a connection? *Journal of Shellfish Research* 15, 203–230.
- Lassalle G., de Montaudouin X., Soudant P. and Paillard C. (2007) Parasite co-infection of two sympatric bivalves, the Manila clam (*Ruditapes philippinarum*) and the cockle (*Cerastoderma edule*) along a latitudinal gradient. *Aquatic Living Resources* 20, 33–42.
- Lauckner G. (1971) Zur trematodenfauna der herzmuscheln *Cardium edule* und *Cardium lamarki*. *Helgoländer Meeresuntersuchungen* 22, 377–400.
- Lauckner G. (1984) Impact of trematode parasitism on the fauna of a North Sea tidal flat. *Helgoländer Meeresuntersuchungen* 37, 185–199.
- Le Grand F., Kraffe E., de Montaudouin X., Villalba A., Marty Y. and Soudant P. (2010) Prevalence, intensity, and aneuploidy patterns of disseminated neoplasia in cockles (*Cerastoderma edule*) from Arcachon Bay: seasonal variation and position in sediment. *Journal of Invertebrate Pathology* 104, 110–118.
- Lebour M.V. (1912) A review of British marine cercariae. *Parasitology* 4, 416–456.
- Lebour M.V. and Elmhirst R. (1922) A contribution towards the life history of *Parorchis acanthus* Nicoll, a trematode in the herring gull. *Journal of the Marine Biological Association of the United Kingdom* 12, 829–832.
- Leigh-Sharpe W.H. (1933) Note on the occurrence of *Graffilla gemelli-para* Linton (Turbellaria) at Plymouth. *Parasitology* 25, 108.
- López-Flores I., Garrido-Ramos M.A., de la Herran R., Ruiz-Rejón C., Ruiz-Rejón M. and Navas J.I. (2008) Identification of *Marteilia refringens* infecting the razor clam *Solen marginatus* by PCR and *in situ* hybridization. *Molecular and Cellular Probes* 22, 151–155.
- Maeno Y., Yurimoto T., Nasu H., Ito S., Aishima N., Matsuyama T., Kamaishi T., Oseko N. and Watanabe Y. (2006) Virus-like particles associated with mass mortalities of the pen shell *Atrina pectinata* in Japan. *Diseases of Aquatic Organisms* 71, 169–173.
- Maillard C. (1975a) Evolutive cycle of *Paratimonia gobii*, Prevot and Bartoli 1967 (Trematoda, Monorchioidea). *Acta Tropica* 32, 327–339.
- Maillard C. (1975b) *Labratrema lamirandi* (Carrère, 1937) (Trematoda: Bucephalidae) parasite de *Dicentrarchus labrax* (L. 1758). Creation du genre *Labratrema*. Cycle évolutif. *Bulletin de la Muséum National d'Historie Naturelle, Paris, Zoologie* 193, 69–80.
- Maillard C. and Saad-Fares A. (1981) *Bucephalus baeri* n. sp. (Trematoda) parasite de *Dicentrarchus labrax* (Teleostei): description et cycle évolutif. *Parasitology Research* 66, 31–40.
- Matthews R.A. (1973) The life-cycle of *Bucephalus haimeanus* Lacaze-Duthiers, 1854 from *Cardium edule* L. *Parasitology* 67, 341–350.
- McDermott J.J. (2006) Nemertean hosts for symbionts: a review. *Journal of Natural History* 40, 1007–1020.
- Mercado-Silva N. (2005) Condition index of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791) in Sapelo Island Georgia—effects of site, position on bed and pea crab parasitism. *Journal of Shellfish Research* 24, 121–126.
- Minchin D. (2003) Introductions: some biological and ecological characteristics of scallops. *Aquatic Living Resources* 16, 521–532.
- Mladineo I. and Peharda M. (2009) Histopathology of *Gymnophallus* sp. sporocysts in the edible mytilid, *Modiolus barbatus*. *Journal of Shellfish Research* 24, 1097–1100.
- Mourgaard Y., Martínez É., Geffard A., Andral B., Stanisiere J.Y. and Amiard J.C. (2002) Metallothionein concentration in the mussel *Mytilus galloprovincialis* as a biomarker of response to metal contamination: validation in the field. *Biomarkers* 7, 479–490.
- Navas J.I., Castillo M.C., Vera P. and Ruiz-Rico M. (1992) Principal parasites observed in clams, *Ruditapes decussatus* (L.), *Ruditapes philippinarum* (Adams et Reeve), *Venerupis pullastra* (Montagu) and *Venerupis aureus* (Gmelin), from the Huelva coast (S.W. Spain). *Aquaculture* 107, 193–199.
- Nicoll W. (1906) Notes on trematode parasites of the cockle (*Cardium edule*) and mussel (*Mytilus edulis*). *Annals and Magazine of Natural History (Series 7)* 17, 147–155.
- Novoa B., Posada D. and Figueras A. (2005) Polymorphisms in the sequences of *Marteilia* internal transcribed spacer region of the ribosomal RNA genes (ITS-1) in Spain: genetic types are not related with bivalve hosts. *Journal of Fish Diseases* 28, 331–338.
- Nowak B.F. and LaPatra S.E. (2006) Epitheliocystis in fish. *Journal of Fish Diseases* 29, 573–588.
- O'Beirn F.X. and Walker R.L. (1999) Pea crab, *Pinnotheres ostreum* Say, 1817, in the eastern oyster, *Crassostrea virginica* (Gmelin, 1791): prevalence and apparent adverse effects on oyster gonad development. *Veliger* 42, 17–20.
- Ordás M.C. and Figueras A. (2005) Histopathological study of abnormal mortalities of cockle (*Cerastoderma edule*) in Carril (Galicia, NW Spain). *Bulletin of the European Association of Fish Pathologists* 25, 124–130.
- Overstreet R.M. and Curran S.S. (2002) Superfamily Bucephaloidea Poche, 1907. In Gibson D.I., Jones A. and Bray R.A. (eds) *Keys to the Trematoda*. Wallingford, UK: CABI, pp. 67–110.
- Paillard C. (2004) A short-review of brown ring disease, a vibriosis affecting clams, *Ruditapes philippinarum* and *Ruditapes decussatus*. *Aquatic Living Resources* 17, 467–475.
- Paillard C., Maes P. and Oubella R. (1994) Brown ring disease in clams. *Annual Review of Fish Diseases* 4, 219–240.

- Palombi A.** (1930) Il ciclo biologico di *Diphtherostomum brusinae* Stossich (Trematode digenetic: fam. Zoogonidae Odhner). Considerazioni sui cicli evolutivi delle specie affini e dei trematodi in generale. *Pubblazioni della Stazione Zoologica di Napoli* 10, 111–150.
- Park K.I., Tsutsumi H., Hong J.S. and Choi K.S.** (2008) Pathology survey of the short-neck clam *Ruditapes philippinarum* occurring on sandy tidal flats along the coast of Ariake Bay, Kyushu, Japan. *Journal of Invertebrate Pathology* 99, 212–219.
- Paul-Pont I., Gonzalez P., Baudrimont M., Jude F., Raymond N., Bourrasseau L., Le Goïc N., Haynes F., Legeay A., Paillard C. and de Montaudouin X.** (2010) Interactive effects of metal contamination and pathogenic organisms on the marine bivalve *Cerastoderma edule*. *Marine Pollution Bulletin* 60, 515–525.
- Pekkarinen M. and Ching H.L.** (1994) Comparisons of gymnophallid digeneans from North Pacific and Baltic clams, *Macoma balthica* (Bivalvia). *Journal of Parasitology* 80, 630–636.
- Pelseneer P.** (1906) Trematodes parasites de mollusques marins. *Bulletin Scientifique de la France et de la Belgique* 40, 161–186.
- Pike A.W. and Burt M.D.B.** (1981) *Paravortex karlingi* sp. nov. from *Cerastoderma edule* L., in Britain. *Hydrobiologia* 84, 23–30.
- Pina S., Barandela T., Santos M.J., Russell-Pinto F. and Rodrigues P.** (2009a) Identification and description of *Bucephalus minimus* (Digenea: Bucephalidae) life cycle in Portugal: morphological, histopathological, and molecular data. *Journal of Parasitology* 95, 353–359.
- Pina S., Tajdari J., Russell-Pinto F. and Rodrigues P.** (2009b) Morphological and molecular studies on life cycle stages of *Diphtherostomum brusinae* (Digenea: Zoogonidae) from northern Portugal. *Journal of Helminthology* 83, 321–331.
- Poder M. and Auffret M.** (1986) Sarcomatous lesion in the cockle *Cerastoderma edule*: I. Morphology and population survey in Brittany, France. *Aquaculture* 58, 1–8.
- Príncipe M., Bigas M. and Durfort M.** (1996) Incidence of *Bucephalus haimeanus* (Lacaze-Duthiers, 1854) (Trematoda, Digenea) in the digestive gland of *Ostrea edulis* Linné. *Iberus* 14, 211–220.
- Príncipe M. and Durfort M.** (1993) Estudio ultraestructural de las fases larvarias de *Bucephalus haimeanus* (Trematoda, Digenea) halladas en el primer huésped intermediario *Ostrea edulis* L. *Miscellaneous Zoology* 17, 35–48.
- Reimer L.W.** (1973) Das auftreten eines fisch-trematoden der gattung *Asymphyllodora* Looss, 1899, bei *Nereis diversicolor* O.F. Müller als beispiel für einen alternativzyklus. *Zoologischer Anzeiger* 191, 187–196.
- Reise K.** (2003) Metapopulation structure in the lagoon cockle *Cerastoderma lamarcki* in the northern Wadden Sea. *Helgoland Marine Research* 56, 252–258.
- Romalde J.L., Vilarinho M.L., Beaz R., Rodriguez J.M., Diaz S., Villalba A. and Carballal M.J.** (2007) Evidence of retroviral etiology for disseminated neoplasia in cockles (*Cerastoderma edule*). *Journal of Invertebrate Pathology* 94, 95–101.
- Russell-Pinto F., Gonçalves J.F. and Bowers E.** (2006) Digenean larvae parasitizing *Cerastoderma edule* (Bivalvia) and *Nassarius reticulatus* (Gastropoda) from Ria de Aveiro, Portugal. *Journal of Parasitology* 92, 319–332.
- Sannia A. and James B.L.** (1978) The occurrence of *Cercaria cerastodermiae* I Sannia, James, and Bowers, 1978 (Digenea: Monorchidae) in populations of *Cerastoderma edule* (L.) from the commercial beds of the Lower Thames Estuary. *Parasitology Research* 56, 1–11.
- Scholz T.** (2002) Family Gymnophallidae Odhner, 1905. In Gibson D.I., Jones A. and Bray R.A. (eds) *Keys to the Trematoda*. Wallingford, UK: CAB, pp. 245–251.
- Soto M., Pascual S., Rodriguez H., Gestal C., Abollo E., Arias C. and Estévez J.** (1996) *Nematopsis* spp. Schneider, 1892 (Apicomplexa: Gregarinida) in bivalve molluscs off Ria de Vigo (Galicia, NW Spain). *Bulletin of the European Association of Fish Pathologists* 16, 157–160.
- Stock J.H.** (1993) Copepoda (Crustacea) associated with commercial and non-commercial Bivalvia in the East Scheldt, The Netherlands. *Bijdragen tot de Dierkunde* 63, 61–64.
- Stossich M.** (1887) Brani di elmintologia tergestina, IV. *Bollettino della Società Adriatica di Scienz Naturali in Trieste* 10, 90–96.
- Stunkard H.W.** (1938) The morphology and life cycle of the trematode *Himastha quissetensis* (Miller and Northup, 1926). *Biological Bulletin. Marine Biological laboratory, Woods Hole* 75, 145–164.
- Stunkard H.W. and Uzzmann J.R.** (1958) Studies on digenetic trematodes of the genera *Gymnophallus* and *Parvatrema*. *Biological Bulletin. Marine Biological Laboratory, Woods Hole* 115, 276–302.
- Subida M.D., Arias A.M., Drake P., Garcia-Raso J.E., Rodriguez A., and Cuesta J.A.** (2011) On the occurrence of *Afropinnotheres monodi* Manning, 1993 (Decapoda: Pinnotheridae) in European waters. *Journal of Crustacean Biology* 31, 367–369.
- Sun J. and Wu X.** (2004) Histology, ultrastructure, and morphogenesis of a *Rickettsia*-like organism causing disease in the oyster, *Crassostrea ariakensis* Gould. *Journal of Invertebrate Pathology* 86, 77–86.
- Sun W., Sun S., Yuqi W., Baowen Y. and Weibo S.** (2006) The prevalence of the pea crab, *Pinnotheres sinensis*, and its impact on the condition of the cultured mussel, *Mytilus galloprovincialis*, in Jiaonan waters (Shandong Province, China). *Aquaculture* 253, 57–63.
- Tennent D.H.** (1906) A study of the life-history of *Bucephalus haimeanus*; a parasite of the oyster. *Journal of Cell Science* s2-49, 635–690.
- Thébault A., Bergman S., Pouillot R., Le Roux F. and Berthe F.C.J.** (2005) Validation of *in situ* hybridisation and histology assays for the detection of the oyster parasite *Marteilia refringens*. *Diseases of Aquatic Organisms* 65, 9–16.
- Thieltges D.W.** (2006) Parasite induced summer mortality in the cockle *Cerastoderma edule* by the trematode *Gymnophallus choledochus*. *Hydrobiologia* 559, 455–461.
- Thieltges D.W.** (2007) Habitat and transmission—effect of tidal level and upstream host density on metacercarial load in an intertidal bivalve. *Parasitology* 134, 599–605.
- Thieltges D.W.** (2008) Effect of host size and temporal exposure on metacercarial infection levels in the intertidal cockle *Cerastoderma edule*. *Journal of the Marine Biological Association of the United Kingdom* 88, 613–616.
- Thieltges D.W., Hussell B., Hermann J., Jensen K.T., Krakau M., Taraschewski H. and Reise K.** (2008) Parasites in the northern Wadden Sea: a conservative ecosystem component over 4 decades. *Helgoland Marine Research* 62, 37–47.
- Thieltges D.W., Krakau M., Andresen H., Fottner S. and Reise K.** (2006) Macroparasite community in molluscs of a tidal basin in the Wadden Sea. *Helgoland Marine Research* 60, 307–316.
- Thieltges D.W. and Reise K.** (2006) Metazoan parasites in intertidal cockles *Cerastoderma edule* from the northern Wadden Sea. *Journal of Sea Research* 56, 284–293.
- Thieltges D.W. and Reise K.** (2007) Spatial heterogeneity in parasite infections at different spatial scales in an intertidal bivalve. *Oecologia* 150, 569–581.
- Thieltges D.W. and Rick J.** (2006) Effect of temperature on emergence, survival and infectivity of cercariae of the marine trematode *Renicola roscovita* (Digenea: Rencolidae). *Diseases of Aquatic Organisms* 73, 63–68.

- Twomey E. and Mulcahy M.F.** (1988) Epizootiological aspects of a sarcoma in the cockle *Cerastoderma edule*. *Diseases of Aquatic Organisms* 5, 225–238.
- van Banning P.** (1979) Protistan parasites observed in the European flat oyster (*Ostrea edulis*) and the cockle (*Cerastoderma edule*) from some coastal areas of the Netherlands. *Haliotis* 8, 33–37.
- Vaullegeard A.** (1900) Etude expérimentale et critique sur l'action des helminthes: I. Cestodes et nématodes. *Bulletin de la Société Linnéenne de Normandie* 5, 84–142.
- Villalba A., Carballal M.J. and López C.** (2001) Disseminated neoplasia and large foci indicating heavy haemocytic infiltration in cockles *Cerastoderma edule* from Galicia (NW Spain). *Diseases of Aquatic Organisms* 46, 213–216.
- Watermann B., Thomsen A., Kolodzey H., Daehne B., Meemken M., Pijanowska U. and Liebezeit G.** (2008) Histopathological lesions of molluscs in the harbour of Norderney, Lower Saxony, North Sea (Germany). *Helgoland Marine Research* 62, 167–175.
- Wegeberg A.M., de Montaudouin X. and Jensen K.T.** (1999) Effect of intermediate host size (*Cerastoderma edule*) on infectivity of cercariae of three *Himasthla* species (Echinostomatidae, Trematoda). *Journal of Experimental Marine Biology and Ecology* 238, 259–269.
- Wegeberg A.M. and Jensen K.T.** (1999) Reduced survivorship of *Himasthla* (Trematoda, Digenea)-infected cockles (*Cerastoderma edule*) exposed to oxygen depletion. *Journal of Sea Research* 42, 325–331.
- Wegeberg A.M. and Jensen K.T.** (2003) *In situ* growth of juvenile cockles, *Cerastoderma edule*, experimentally infected with larval trematodes (*Himasthla interrupta*). *Journal of Sea Research* 50, 37–43.
- Zander C.D.** (1998) Ecology of host parasite relationships in the Baltic Sea. *Naturwissenschaften* 85, 426–436.
- and
- Zander C.D. and Reimer L.W.** (2002) Parasitism at the ecosystem level in the Baltic Sea. *Parasitology* 124, S119–S135.

Correspondence should be addressed to:

M. Longshaw
Cefas Weymouth Laboratory
Barrack Road, The Nothe, Weymouth, Dorset, DT4 8UB
email: matt.longshaw@cefas.co.uk