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Editorial

Diseases of commercially exploited crustaceans: Cross-cutting issues for global fisheries and aquaculture

1. A global industry

The Food and Agricultural Organisation (FAO) of the United Nations predict that annual production of wild capture and farmed crustaceans exceeds 10 million metric tonnes with a first sale value of almost $40bn. Fisheries contribute approximately 60% by weight and 50% by value, with aquaculture production forming the remainder. Fisheries are dominated by marine shrimp ($12bn), crabs ($3.7bn), lobsters ($2.4bn) and freshwater crustaceans ($1bn) (http://www.fao.org). Marine shrimp form the most significant proportion of the aquaculture (3 m metric tonnes, first sale value $12bn), with freshwater crustaceans ($4.7bn), and other miscellaneous species contributing the rest (data for 2006; http://www.fao.org). Whilst fisheries production has remained largely stable in recent years, the aquaculture production of species such as the Pacific white shrimp (*Penaeus vannamei*) have undergone rapid global expansion since 2000, now ranking in the top 10 species by production quantity and number one for production value ($9bn). The tiger shrimp (*Penaeus monodon*) adds a further $3bn per year in production value (http://www.fao.org). Production of cultured crustaceans is predominantly focussed in Central and South America and in the Asian sub-continent. Consumption of product is however, focussed in the USA, Japan and particularly the European Union. The geographic separation of net consuming and net producing nations for crustaceans has therefore led to a globalised industry in which live animals and their products are moved across international boundaries, both for ongrowing and for direct consumption.

In nations where fisheries production dominates (e.g. those of the European Union), wild crustaceans are commonly transported live within country or internationally for resale and consumption. To date, the movement of live crustaceans in this way has been relatively uncontrolled, with losses in transport remaining unrecorded and morbid or dead animals potentially being disposed of in the aquatic environment of the receiving site. Previously, we have highlighted how the dearth in knowledge of pathogens of even our most important commercially exploited crustacean species identifies these as high risk practices (Stentiford and Shields, 2005). At least within Europe, these broader issues of risk associated with the movement of live crustaceans and their products have for the first time been included in legislative instruments to protect the health status of wild and cultured crustaceans in European Union Member State waters (see Stentiford et al., 2009, 2010). With such legislation comes an increasing requirement to understand the pathogen profile of commercially important species of crustaceans. Furthermore, international legislation provides a driving force to better understand the health factors that limit production in aquaculture and encourage a shared responsibility between net consuming and net producing nations for the safe production and movement of live animals and their products.

2. Reviewing important diseases of crustaceans

The papers in this special issue provide an overview of key issues regarding infection and disease in commercially important crustacean taxa. Several of the papers concentrate on pathogens of concern to significant global fisheries for crabs, lobsters and crayfish while others review the current state of knowledge with regard diseases of farmed crustaceans, both in marine and freshwaters. The literature concerning the description of pathogenic agents in crustaceans is perhaps most replete for the crabs, largely due to the fact that numerous species are either fished commercially, are accessible to the researcher, or are apparently inflicted by a wide range of pathogens for study (compared for instance, to the homarid lobsters). In their review of crab viruses, Bonami and Zhang highlight the fact that virus research in wild crabs in Europe formed the basis from which modern crustacean virology emerged, and further that a wide taxonomic spectrum of viral agents are an apparently important mortality factor for individuals and populations. In her review, Wang expands upon these data by demonstrating how bacteria (e.g. spiroplasms) have been identified as important emerging pathogens in cultured crabs in Asia. Morado reviews the important protistan pathogens of crabs (such as *Hematodinium* spp.) and demonstrates how such infections, and the diseases that they cause, have clear detrimental effects on the sale and marketing of diseased animals but further, how their effects at the population level are much less understood. These potential 'silent mortalities' in the fishery are also covered in the review of diseases of the lobster genera *Nephrops* and *Metanephrops* by Stentiford and Neil. Once again, *Hematodinium* sp. is highlighted as the key (known) pathogen in fished populations of *Nephrops* in Europe, while the recent discovery of a taxa of microsporidian (*Myospora metanephrops*) in deep water *Metanephrops challengeri* from New Zealand demonstrates that we still know relatively little about pathogens and their effects in our key fisheries species. Cawthorn, reviewing diseases in homarid lobsters discusses the role of environmental and anthropogenic forcing factors in lobster health, highlighting current issues with the apparently syndromic epizootic shell disease in the large eastern Atlantic fishery for *Homarus americanus*. Shields, in his review of diseases in spiny lobsters, provides an excellent example of a potentially emerging disease issue in *Panulirus argus*. So-called *P. argus* virus

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1 (PAV1) is predominantly a pathogen of juvenile life stages in this lobster species and may be spreading through the Caribbean via the movement of early life stages and their use by fishers as live 'baits' for capturing adults of this species. Studies on this virus have exposed a basic lack of understanding of pathogenic agents and their effects in juveniles of important commercially exploited crustaceans and further, how mortality drivers in juvenile life stages affect the eventual recruitment of animals into the fished population.

In terms of crustacean aquaculture, Lightner highlights the historic role of viral agents in limiting the global production of penaeid shrimp and provides a series of examples, spanning several decades, of emerging pathogens in this global industry (concentrating on the Americas). The pandemic nature of the major penaeid shrimp viruses such as White Spot Syndrome Virus (WSSV), and the emergence of novel agents (such as Infectious Myonecrosis Virus, IMNV) are now recognised as severe limiting factors for the global shrimp industry. The Lightner review provides an overview of attempts at mitigating these effects within production zones, largely by improved biosecurity, husbandry and the increasing usage of specific pathogen free (SPF) and specific pathogen resistant (SPR) stocks. As stated above, the increased legislative mechanisms being put into place by organisations such as the World Organisation for Animal Health (OIE), and via international legislation such as that being enforced within the European Union, is providing further impetus to improve transboundary control of newly emerging pathogens in this industry. Bonami and Sri Widada follow this theme by over-viewing the state of knowledge concerning viral pathogens in farmed freshwater shrimp (*Macrobrachium rosenbergi*). Here, infection by *M. rosenbergi* nodavirus (*Mr*NV) and a non-autonomous satellite-like virus (XSV) causes the condition White Tail Disease (WTD). Similar to other viral shrimp pathogens, the viruses causing WTD have been responsible for mass mortalities and important economic losses in hatcheries and farms for over a decade and have recently been listed as notifiable by the OIE. In terms of freshwaters, crayfish diseases are reviewed by Longshaw, and in a unifying theme, he details their wide pathogen range, a requirement to understand mortality drivers in addition to those disease agents most well studied in the literature (e.g. crayfish plague caused by *Aphanomyces astaci*), and a basic paucity in taxonomic expertise available for accurate and rapid diagnostics for existing and novel pathogens of crustaceans.

Two final reviews consider broader issues concerning disease agents and their interaction with crustacean hosts. In their review, Small and Pagenkopp provide a series of examples of the role of alternative and reservoir hosts for crustacean pathogens; an issue often overlooked when studying disease processes in commercially exploited species. Some viral agents, such as WSSV, provide obvious examples of broad host-range viruses that can reside in hosts and habitats beyond the temporal limits of overt outbreaks. However, the seasonal nature of some pathogens of wild crustaceans (such as *Hematodinium* spp.) is suggestive of their presence in alternative hosts or reservoirs in the observed 'low seasons'. These issues are understudied and potentially of significance to the mitigation of the effects of these pathogens in wild commercial stocks. Finally, Fotedar and Evans address issues of health and welfare in wild captured crustaceans destined for the live market, during the post-harvest period. Clearly the underlying condition (e.g. moult status) and health status of animals at point of capture is a key driver in their likelihood of reaching market. However, in some sectors, poor practice in initial animal grading and in subsequent handling leads to significant losses in the post-harvest period. Large percentage losses in the post-capture/pre-market phase can lead to unsustainable over-exploitation in the capture phase. This review highlights a requirement to improve practice with regard post-capture handling of live crustaceans.

3. Future challenges and solutions

Despite the wide spectrum in host and pathogen taxonomy covered by these reviews, they each provide a clear demonstration of the detrimental effects of disease agents in farmed and wild populations of crustaceans. Furthermore, numerous examples are provided of the potential for the anthropogenic spread of pathogenic agents in live animals and their products. The pandemic nature of most of the major viral pathogens of farmed shrimp, and of some parasites (such as *Hematodinium* spp.) in wild stocks, raises issues over current commercial practices and further, provides a catalyst for improvements in industrial operations that produce food from these sectors. In summary, infectious disease forms a significant negative contribution to the historic and current production, exploitation and trading of farmed and fished crustaceans. Some disease agents (such as White Spot Syndrome Virus, WSSV) have been distributed globally with traded crustaceans and are now endemic barriers to production in all known production zones. WSSV alone has been responsible for at least $10bn in lost production of farmed penaeid shrimp since it's emergence in the early 1990s and it is estimated that 40% of current tropical shrimp production is lost due to infectious diseases each year (Lundin, 1996). Concern over the spread of pathogens such as WSSV with the global trading of live crustaceans and their products has led to their recent listing in European legislation concerning the trading of aquatic animals (EC Directive 2006/88/EC). This listing highlights the transboundary transmission potential of such pathogens (even in food products) and further, introduces the potential for trading barriers between net producer and net consumer nations (Stentiford et al., 2009, 2010).

If the global crustacean industry is to continue to provide part of a long-term solution for international food security from the aquatic sector, it is important that fundamental issues related to disease and its mitigation, are tackled in a coordinated manner. As such, a linkage between industry specialists (in the culture, capture and trading of crustaceans), pathologists, epidemiologists, therapeutics experts, and policy makers in the field of food security, is required. Unique challenges, largely related the absence of a vaccination response in crustacean hosts, face the crustacean aquaculture sector. Recent efforts have been applied to the development of novel therapeutic strategies for specific viral pathogens, such as those based upon the 'RNA interference' (RNAi) approach. An improving picture on the fundamental elements of crustacean immunology will assist with such approaches, as will moves towards the sequencing of complete genomes for those species most commonly farmed, particularly the penaeid shrimp. Several of these issues are also common to the wider field of terrestrial invertebrate pathology (e.g. related to the role of pathogens and other environmental forcing factors in the global decline in populations of pollinating insects). For this reason, the Society of Invertebrate Pathology has recently established a new Division (Diseases of Beneficial Invertebrates) that has a focus on pathogens of ecologically or commercially important invertebrates that are generally considered as non-pest species. In essence, this covers aquatic crustaceans and molluscs exploited as fisheries products, other aquatic crustaceans and molluscs with important positions in food chains, farmed crustaceans and molluscs, terrestrial pollinating invertebrates and other invertebrates occupying terrestrial niches considered to be ecologically or economically beneficial to the human population. The new Division will focus on common themes in the pathology and host–pathogen interface across these beneficial host groups and further, will attempt to address significant 'bigger picture' issues that can be studied via these relationship e.g. changing climate, ocean acidification, transboundary disease processes. Cross-cutting expertise, as highlighted above, is a likely requirement in dealing with the challenge for sustainability in the globalised crustacean industry.

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