Bonamia Response 2015:

Report from the Technical Advisory Group on

Resilience Breeding in Flat Oysters

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Purpose of this document is to report on the discussion of the Technical Advisory Group held for the purpose of providing technical advice to support MPI's response to *Bonamia ostreae* in New Zealand.

Table of Contents

Executive summary

Bonamia ostreae is an unwanted and notifiable organism that was first detected in New Zealand in flat oysters (*Ostrea chilensis*) collected in 2014 from the Marlborough Sounds. It is not known how *B. ostreae* entered New Zealand. Evidence indicates that it is a recent introduction. A Controlled Area Notice was issued as a measure to prevent the spread of *B. ostreae* from the known infected area to valuable wild oyster populations and farmed oysters in Big Glory Bay (Stewart Island). In May 2017, MPI's surveillance programme detected *B. ostreae* in farmed oysters from Big Glory Bay. The decision was made to depopulate all oyster farms in Big Glory Bay and the Marlborough Sounds to protect the wild flat oyster population in Foveaux Strait and contain the spread of infection to other areas. The aquaculture industry requested that MPI consider retaining some stock from the Marlborough Sounds farms for the purpose of breeding *B. ostreae* resilient oysters. The oysters to be retained were stock that had survived *B. ostreae* mortality events and were considered by some oyster farmers and Cawthron scientists to be *B. ostreae* resilient. The premise for the proposal was that a "*selective breeding programme could potentially future-proof and rebuild wild oyster fisheries by increasing the resilience of the populations even in the absence of the parasite, so that in the event of future incursions flat oysters would be more able to survive infections*". The proposed programme was also put forward as a way to future-proof and support the reestablishment of *O. chilensis* aquaculture.

In response to this proposal a Technical Advisory Group (TAG) was assembled by MPI to provide independent, expert scientific and technical advice on *Bonamia* spp. resilience breeding in flat oysters. The TAGs discussions were conducted in the context of *Bonamia ostreae* being an unwanted organism in New Zealand, with a distribution of infection that is highly localised. The understanding of the TAG was that the highest priorities were the ongoing containment of *B. ostreae* and the protection of wild populations of *O. chilensis* from *B. ostreae* infection.

Conclusions and recommendations

1. The TAG was of the opinion that preventing the spread of *B. ostreae* to wild fisheries and uninfected cold water sites suitable for flat oyster aquaculture would provide the greatest benefits to wild populations and the wild harvest industry, and to flat oyster aquaculture in areas that remain *B. ostreae* free;
2. The enhanced risk posed to wild *O. chilensis* populations by the remaining *B. ostreae* infected farmed stock in the Marlborough Sounds is real, and remaining oysters should to be removed as soon as possible;
3. Any in-water resilience breeding programme would increase the risk of *B. ostreae* being spread to uninfected wild oyster populations. Consequently any breeding programme should be conducted in a biosecure land-based facility;
4. Whether or not the surviving Marlborough Sounds flat oysters represent a resilient stock is uncertain. Several factors may have influenced the survival of these oysters including heritable resilience, the health of individual oysters, exposure to the parasite and environmental factors suppressing the development of disease. Controlled challenge trials are required to assess resilience.
5. It is unlikely that the proposed programme could lead to protection or enhancement of the wild fishery. Attempts to enhance the Foveaux Strait fishery through reseeding and habitat enhancement were made in the 1990s and the mid-2000s with no perceivable benefit to the fishery. There is currently no information to suggest that any future reseeding programme would be more successful than the attempts already undertaken;

6. It is likely to be possible to breed flat oysters that are resilient to both *B. ostreae* and the endemic *Bonamia exitiosa,* although this has not previously been attempted. There are a number of significant breeding challenges to overcome before *Bonamia* spp. resilient oysters can be produced. *Bonamia ostreae* resilient flat oysters (*Ostrea edulis*) have been produced in Europe;
7. Basic ecological, epidemiological, immunological and pathological information about *B. ostreae - O. chilensis* interactions are currently lacking. The TAG encourages research into the life-histories, genetics and genomics of the oysters and their parasites, host–parasite interactions and the factors impacting on this dynamic from the perspective of restoration and industry needs. Samples from surviving oysters considered putatively resilient should be examined now or stored for future molecular analysis of relevant genetic characteristics.

Should *B. ostreae* become established more broadly in New Zealand and important wild fisheries suffer the expected negative impacts, the risks associated with an in-water disease resilience breeding programme would be greatly reduced. In-water disease challenges and/or selective breeding for *B. ostreae* resilience could then be initiated. Such a programme would require significant long term investment.

This report documents the TAG's discussion and recommendation to advise the Response Controller on the establishment of a *B. ostreae* resilience breeding programme. The report was drafted by Phil Ross on behalf of the TAG. TAG members contributed to the drafting and have reviewed the document to ensure it is an accurate reflection of the discussions held.

1. Introduction

1.1. Purpose of this document

The Ministry for Primary Industries (MPI) identified the need for a Technical Advisory Group (TAG) to provide expert scientific and technical advice and guidance to MPI's response on the scientific feasibility, biosecurity risks, and general requirements of a *Bonamia* resilience breeding programme for flat oysters (*Ostrea chilensis*). This document reports on the discussions of the TAG meetings convened in August and September 2017. The recommendations of the TAG are also included.

1.2. Background

Bonamia ostreae is an unwanted and notifiable organism in New Zealand that was first detected in flat oysters (*Ostrea chilensis*) collected in 2014 from the Marlborough Sounds. A Controlled Area Notice (see Controlled Area Notice at http://www.mpi.govt.nz/protection-and-response/responding/alerts/bonamia-ostreae /) was issued as a measure to prevent the spread of *B. ostreae* from the known infected area to valuable wild oyster populations and farmed oysters in Big Glory Bay (Stewart Island). After initial delimiting and surveillance surveys (April 2016) *B. ostreae* infection was detected in oyster farming operations and in scattered low-density wild populations in Queen Charlotte and Pelorus Sounds (Contained Zone). Prevalence on farms was 2-30%, and 7-44% in wild populations (Anderson et al. 2016). A second surveillance survey in September 2016 found prevalence of *B. ostreae* infection in farmed oysters in Queen Charlotte Sound was generally high and up to 100% (Michael et al. 2017).

No infections were detected in wild oyster populations in Cloudy Bay near to Port Underwood (stock OYS 7C) or in Tasman and Golden Bays (stock OYS 7). The Protected Zones (Southland, including the Foveaux Strait population OYU5, Otago, and the Chatham Islands OYS4) and the North Island were free from *B. ostreae*. No spread of infection was detected between the first and second surveys. High mortalities, of up to 95%, were observed in farmed oysters in the Queen Charlotte Sound.

In May 2017, MPI's surveillance programme detected *B. ostreae* in farmed oysters from Big Glory Bay, Stewart Island, close to the Foveaux Strait (26% prevalence, Anderson et al. 2017). The decision was made to depopulate all oyster farms in Big Glory Bay (designated a single epidemiological unit) and the Marlborough Sounds to protect the wild flat oyster population in Foveaux Strait, a fishery of national importance (Michael et al. 2016) and one of the last remaining wild flat oyster fisheries in the world that is not augmented through reseeding or habitat enhancement. The aquaculture industry requested that MPI consider retaining some stock from the Marlborough Sounds farms for the purpose of breeding *B. ostreae* resilient oysters (Hilton et al. 2017). The oysters to be retained were stock that had survived *B. ostreae* mortality events and were considered by some oyster farmers and Cawthron scientists to be *B. ostreae* resilient. The premise for the proposal was that a "*selective breeding programme could potentially future-proof and rebuild wild oyster fisheries by increasing the resilience of the populations even in the absence of the parasite, so that in the event of future incursions flat oysters would be more able to survive infections*". The proposed programme was also put forward as a way to future-proof and support the reestablishment of *O. chilensis* aquaculture.

In response to this proposal to breed *B. ostreae* resilient flat oysters, a Technical Advisory Group (TAG) was assembled by MPI to provide independent, expert scientific and technical advice on *Bonamia* spp. resilience breeding in flat oysters.

2. Purpose of the Technical Advisory Group (TAG)

MPI convened a Technical Advisory Group (TAG) in August and September 2017. The purpose of the TAG was to provide open and frank, independent, expert scientific and technical advice on *Bonamia* resilience breeding in flat oysters, including:

- Advice on the feasibility of a *Bonamia* resilience breeding programme;
- Advice on the requirements for establishing an effective programme for *Bonamia* resilience breeding in flat oysters, including available tools, techniques and recommended facilities;
- Advice on the biosecurity risks posed to farmed and wild oyster populations by establishing a *Bonamia* resilience breeding programme in New Zealand considering land and sea-based options;
- Objective evaluation and comment on the likelihood of being able to establish a resilience breeding programme that leads to protection of the wild fisheries and a commercially viable outcome; and
- Scientific / technical recommendations on the most appropriate course of action.

3. TAG meeting processes and objectives

The TAG comprised seven experts on *Bonamia*, aquatic animal health, disease resilience and selective breeding in bivalves, fisheries and marine ecology (Appendix 1). TAG members were sent a Terms of Reference document and a range of relevant pre-meeting reading material. The first meeting of the TAG was held 23-24 August 2017. The meeting involved two half day workshops for the TAG, a site visit to the Cawthron Aquaculture Park and a half day workshop with Cawthron researchers and representatives of the [redacted] oyster companies to discuss the proposed resilience breeding programme. There was no communication with, or representation from wild oyster fisheries stakeholders. Prior to discussions commencing on 23 August, a background to the New Zealand flat oyster industry (aquaculture and wild harvest) and *Bonamia* spp. were presented as was a summary of the 2015 *B. ostreae* response and an overview of the 2017 response to the detection of *B. ostreae* in Big Glory Bay. A second TAG meeting was convened by MPI on 1 September 2017 via tele-conference to further consider the proposal, to hold discussions with TAG members unable to attend the first workshop, and to make recommendations relating to the proposal to breed *B. ostreae* resilient flat oysters.

The TAG were provided with a set of questions to address during the TAG meetings but were permitted to expand or change these questions based on their discussions. The specific questions provided to the TAG were as follows:

1. Is it possible to breed oysters that are concurrently resilient to *Bonamia ostreae* and *Bonamia exitiosa*?

2. Could a resilience breeding programme be conducted in a biosecure way that would not enhance the risk of spread of *B. ostreae* to uninfected wild oyster populations?

3. What would such a resilience breeding programme look like?

4. What biosecurity risks would need to be managed?
    a. How would those risks be best managed?

   b. What would be the residual level of risk of disease spread?

5. Do the farmed oysters currently present in Marlborough represent an important source of resilient stock that should be preserved in part for a breeding programme?
   a. If yes, what would be the recommended process for doing this?
   b. How could biocontainment be obtained?
   c. What scale of operation would be needed, e.g. how many oysters should be preserved?

6. Could a resilience breeding programme lead to protection and recovery of the wild fisheries?
   a. If yes, what duration of time could be expected before demonstrable recovery?

7. Is it expected that a resilience breeding programme could lead to a commercially viable outcome?
   a. If yes, what duration of time could be expected before the investment may lead to profits?

The face to face meeting in August was facilitated by John Appleby and the September tele-conference was facilitated by Nicky Fitzgibbon. Observers from MPI were present at both meetings.

4. Discussion and recommendations

The discussions of the TAG have been conducted in the context of *Bonamia ostreae* being an unwanted organism in New Zealand, with a distribution of infection that is highly localized. The understanding of the TAG is that the highest priorities are the ongoing containment of *B. ostreae* and the protection of wild populations of *O. chilensis* from *B. ostreae* infection.

It is not known how *B. ostreae* entered New Zealand. Evidence indicates that it is a recent introduction. Infection was probably spread between two key farm areas in the Marlborough Sounds (Tory Channel and Port Underwood) and the Cawthron Aquaculture Park by human vectors transferring infected material; the sequence of infection among sites is not known. The spread of *B. ostreae* to low density scattered wild populations in Queen Charlotte Sound and the outer Pelorus Sounds most likely occurred by waterborne infection. There has been no spread of infection from the initial delimiting survey in April 2016, except to the distant Big Glory Bay farm sites on Stewart Island in May 2017 (Anderson et al. 2016, Michael et al. 2017, Anderson et al. 2017). Because infection was not detected in Big Glory Bay in September 2016, and was detected with high prevalence on one farm site in May 2017, a human vector (intentional or unintentional) is suspected.

There is a high likelihood that the response to the 2017 Big Glory Bay detection (aided by the apparent limited natural dispersal capacity of *B. ostreae*) has contained the infection within Big Glory Bay. No infection has been detected in oysters sampled from the Foveaux Strait fishery in February 2017 and June 2017, from Bluff Harbour in June 2017, and from a hatchery and two farms located off Horseshoe Bay (Stewart Island) in June and August 2017. Additionally, no infection has been detected in wild *O. chilensis* populations in Tasman Bay, Golden Bay, Cloudy Bay, Chatham Islands and Otago. The TAG are of the opinion that *B. ostreae* could be contained within Big Glory Bay and the Marlborough Sounds given the absence of spread observed in the Marlborough Sounds to date and the low densities of flat oysters that occur in naturally in these areas. Eradication of *B. ostreae* from these areas is unlikely. The European experience is that eradication programmes, even sustained over several years, may not be successful as indicated by the re-emergence of *B. ostreae* following the reintroduction of oysters to previously infected sites (Van Banning 1985, 1987). Should *B. ostreae* become endemic in wild populations outside of the Marlborough Sounds and Big Glory

Bay in the future, then the risks associated with the proposed *B. ostreae* breeding programme would be altered and the TAG's conclusions and recommendations recorded in this report might change. A commentary of the topics discussed in the two TAG meetings are set out below together with the TAG's recommendations.

4.1. Could a resilience breeding programme be conducted in a biosecure way that would not enhance the risk of spreading *B. ostreae* to uninfected wild oyster populations?

The TAG acknowledged there is little information on host–parasite interactions between *O. chilensis* and *B. ostreae.* Interactions may be similar to those between *Ostrea edulis* and *B. ostreae*, and more severe than those between *O. chilensis* and *B. exitiosa*. The nature of these interactions warrants study to elucidate it definitively. Selective breeding of *O. chilensis* is challenging (Joyce et al. 2015, Nick King (Cawthron Institute) *pers. comm*.). Any potential benefit of a resilience breeding programme for *B. ostreae* is likely to be costly and a long term programme, even in the absence of a biosecurity risk (Hilton et al. 2017).

The TAG spent some time considering whether leaving *B. ostreae* infected oysters in-water in the Marlborough Sounds was compatible with the priorities of containing *B. ostreae* and preventing spread to uninfected wild populations? This question was considered by the TAG to be of fundamental importance to the review of the proposal and was discussed at great length. The spread of *B. ostreae* through non-human assisted mechanisms (e.g. natural dispersal) over long distances was considered unlikely based on the limited spread observed in the Marlborough Sounds to date and historical patterns of *Bonamia* spread in the northern hemisphere (Rodgers et al. 2011; Hill-Spanik et al. 2015). Human mediated transport, either intentional or accidental, is the most likely mechanism by which *B. ostreae* could spread over long distances or to new locations, particularly in the absence of infection at sites between infected areas. The spread of *B. ostreae* to Big Glory Bay, *c.* 900 km south of the Marlborough Sounds, is unlikely to have occurred through natural dispersal pathways. Human-mediated transmission is a more likely explanation. Human-mediated pathways include the intentional or accidental translocation of infected oysters (adult or spat), vessel fouling, and the translocation of *B. ostreae* on infected equipment or in other marine organisms (either as true reservoir hosts or as mechanical vectors). Based on international experiences of human spread of *B. ostreae* and other pathogens (Pernet et al. 2016), and the failure to contain *B. ostreae* to the Marlborough Sounds in New Zealand, the TAG agreed that leaving farmed oysters known to be infected with *B. ostreae* in the water poses an increased and therefore unacceptable biosecurity risk.

The depopulation of all flat oyster farms in the Marlborough Sounds would not eliminate the potential for either natural or human assisted spread beyond the containment area as *B. ostreae* would still be present in wild oyster populations. However, it is the opinion of the TAG that the risk of spread associated with farmed oysters is greater than the risk associated wild populations because of the lower densities at which wild oysters occur (Krkoŝek 2010, Flannery et al. 2014), the potentially lower rates of infection and mortality among wild oysters compared to farmed specimens (Wilkie et al. 2013, Mydlarz et al., 2006), and because of the increased likelihood of human mediated spread from farms. The TAG concluded that any in-water resilience breeding programme would enhance the risk of *B. ostreae* being spread to uninfected wild oyster populations, including those in Foveaux Strait. Consequently, an in-water breeding programme was considered counter to the objectives of containment of *B. ostreae* and protection of wild population and is not recommended. The TAG recommends depopulation of all *B. ostreae* infected flat oyster farms as soon as possible and that any *B. ostreae* resilience breeding programme be conducted in a biosecure land-based facility.

4.2. What biosecurity risks would need to be managed? How would those risks be best managed? What would be the residual level of risk of disease spread?

Should a *B. ostreae* resilience breeding programme be established, the only way in which it could be biosecure would be to have it conducted entirely in an appropriate land-based containment facility with suitable physical and biosecurity containment practises. This arrangement would still pose a real but negligible risk of transmission to wild populations. Catastrophe such as earthquake, tsunami or human error, including deliberate release would remain the most substantial residual containment risks.

In the absence of a resilience breeding programme, there are experiments that could be conducted in biosecure way to progress our knowledge of flat oyster disease resilience. Research could be conducted to investigate the ecology and resilience to the disease by analysing currently exposed wild oysters on shores adjacent to infected lease areas, as well as oysters in unexposed sites. Understanding host reaction (physiological, immunological) to the presence or absence of the parasite would inform on the oysters' ability to fight infection. Molecular analyses of these geographically separated wild oyster populations might provide information about biomarkers that distinguish exposed, and hence potentially resistant oysters, compared to non-exposed and presumably less resistant populations (Simonian et al. 2009; Vaibhav et al. 2016). Knowing which markers contribute to resilience may enable the identification, selection and even breeding of putatively resilient oysters at non-infected locations with lesser *B. ostreae* biosecurity risk (Gomez-Chiarri et al. 2015). Furthermore, tissue preservation of depopulated infected oysters, and wild infected/exposed oysters would be valuable for similar molecular analyses in the future. While this approach would not produce resilient oysters, it would provide much needed knowledge of host–parasite interactions and might be useful in identifying which qualities could be targeted for a breeding program in the future.

4.3. Could a resilience breeding programme lead to protection and recovery of the wild fisheries? If yes, what duration of time could be expected before demonstrable recovery?

The main premise of the resilience breeding programme is that it would potentially future-proof and rebuild wild oyster fisheries. The TAG consider it unlikely that the proposed programme could lead to protection or enhancement of the wild fishery. For restoration of the wild fishery to be successful two main challenges must be overcome. First, successful seeding of aquaculture reared animals into wild populations. Second, introgression of farmed animals into wild populations. The Foveaux Strait oyster fishery occurs in deep water (25-50m) and is exposed to high swell energy (Michael 2010). Shifting sediment (coarse calcareous sand over gravels) exacerbates the high mortality (*c.* 90%) of spat (Cranfield 1979, Michael 2011). High levels of mortality from environmental factors, predation and density dependent processes occur routinely regardless of disease.

Attempts to enhance the Foveaux Strait fishery were made in the 1990s and the mid-2000s (Michael 2011), prior to the arrival of *B. ostreae*. Enhancement was attempted through the reseeding of Foveaux Strait oyster beds and enhancement of recruitment habitat. These endeavours resulted in no perceivable benefit to the fishery. The failure of these programmes is thought to largely be a consequence of the high wave exposure and high rates of natural mortality experienced by Foveaux Strait oysters, independent of disease mortality. There is currently no information available to suggest that any future reseeding programme would be more successful than the attempts already undertaken. Even if a successful method of reseeding could be developed, a restocking program at the scale required for fisheries restoration or enhancement would be possible but prohibitively expensive.

The challenges of integrating farmed oysters into wild populations are demonstrated in Sydney Harbour where the genetic introgression of selectively bred oysters into wild populations has not occurred (Thompson et al. 2017). Even if it were possible to successfully introduce *B. ostreae* resilient oysters into Foveaux Strait it cannot be assumed that resilience would be incorporated into the wider population and generate *B. ostreae* resilience at a population, regional or national level.

Despite the challenges to restoration outlined above, should *B. ostreae* spread to wild populations resulting in mass mortalities and severe declines in wild population abundances, an attempt at enhancement through the reseeding *Bonamia* spp. resilient oysters may be deemed necessary or desirable. Should reseeding and introgression be achieved there is still no certainty of long term success. Disease mortality in *O. chilensis* is multifactorial with environmental and climatic factors playing a role in bonamiosis (Hine et al. 2002, Burreson and Ford 2004). A number of pathogens can cause mortality in *O. chilensis* (see Hine et al. 1986) and two or more parasites may interact with each other (and with environmental factors) to cause heightened mortality (Hine 2002a). It is possible that the selection of *O. chilensis* genotypes exhibiting resilience to *B. ostreae* resilience may have unintended consequences for general disease resilience and fitness.

4.4. Do the farmed oysters currently present in Marlborough represent an important source of resilient stock that should be preserved in part for a breeding programme?

Whether the surviving Marlborough Sounds flat oysters represent a resilient stock is uncertain. An *O. edulis* breeding programme for *B. ostreae* resilience was successfully established in Ireland using 3 to 4 year old survivors as broodstock for controlled spawning in land-based spatting ponds (Lynch et al. 2014). As a result of this programme which commenced in the early 1980s and ran for a number of generations *O. edulis* mortalities in aquaculture are now negligible during the first four years of growth, the prevalence of *B. ostreae* is low and there is no correlation between prevalence of infection and oyster mortality. Regardless of the success achieved in Ireland there is no certainty that the surviving Marlborough Sounds oysters are *B. ostreae* resilient. There are several factors which might influence the oysters' survival including heritable resilience, the health of individual oysters, exposure to the parasite and environmental factors suppressing the development of disease. Research into the phenotype and genotype of survivors in correlation to disease episodes would provide an understanding as to whether these populations represent a resilient stock as survival does not necessarily imply resilience. For example, *B. exitiosa* has caused cyclic mortalities of wild *O. chilensis* in Foveaux Strait on three occasions since 1986. In each mortality event about 10% of oysters have survived, and the wild population has subsequently rebuilt. Despite this process, the Foveaux Strait populations appear no more resilient to the pathogen than previous generations. For *O. chilensis* in Foveaux Strait, surviving a *B. exitiosa* mortality event does not appear to imply heritable resilience.

Resilience breeding programs rely on survival and low intensities of infection (i.e. low number of parasites in infected oysters) as responses variable to measure the heritability of disease resilience and therefore which parents to breed from. It has only been recently that genetic tools have been available to complement phenotypic observations. While the survival of some Marlborough Sounds farmed oysters could potentially be a consequence of resilience with a genetic basis, their survival could also be a consequence of differences in the condition or health of individual animals, uneven exposure to pathogens or some other environmental variable. There are examples from a range of shellfish (and other wildlife) where individuals who survive mortality events are subsequently challenged in the laboratory or *in situ* and have proven no more resilient than naïve individuals. For example, Crane et al. (2013) working with wild abalone in Victoria, Australia, found that survival did not represent resilience to abalone viral ganglioneuritis. To determine resilience requires controlled challenge trials.

The putative benefits of maintaining these infected oysters in an in-water breeding programme do not at present outweigh the risk they present to the wild fishery. It is the opinion of the TAG that the loss of the putatively resilient oysters would not be detrimental to future breeding programmes. Genetic research could commence immediately in a biosecure manner to progress our knowledge of flat oyster disease resilience. Should *B. ostreae* become endemic and an in-water *B. ostreae* resilience breeding programme be instigated in the future, surviving wild oysters (from the Marlborough Sounds, Foveaux Strait or elsewhere) could be considered as putatively resilient and used as broodstock. Alternatively, naïve oysters could be exposed to *B. ostreae* and survivors selected as broodstock.

To facilitate genomic analyses, tissue samples from putatively resilient oysters should be preserved. This approach might assist in identifying any genetic markers for disease resilience and determining if these surviving oysters do indeed have greater resilience than non-survivors. Similarly, tissue samples from surviving wild oysters should also be preserved. Selective breeding might be accelerated with genetic markers if we know the molecular basis for resilience (Vaibhav et al. 2016; Goncalves et al. 2017).

4.5. Is it possible to breed oysters that are concurrently resilient to *Bonamia ostreae* and *Bonamia exitiosa*?

Although the TAG have some reservations about the potential for a resilience breeding programme to rebuild or protect the wild fishery (detailed above), we do believe that it could be possible to breed flat oysters that are resilient to both *B. ostreae* and the endemic *B. exitiosa,* because immune mechanisms in *Ostrea* spp. infected with *B. existiosa* and *B. ostreae* are the same (Martin-Gomez et al. 2012). However, the production of oysters resilient to both *Bonamia* spp. this has not previously been attempted. There are a number of significant breeding challenges to overcome before *Bonamia* spp. resilient *O. chilensis* can be produced. These include difficulties that arise as a consequence of *O. chilensis'* reproductive strategy (Joyce et al. 2015), for example the brooding of larvae (Alipia et al. 2014), and because of our limited understanding of host–parasite interactions for *O. chilensis* and *B. ostreae*.

The value of a breeding programme for resilience to *B. exitiosa* alone was also considered by the TAG. Because *B. exitiosa* is endemic in New Zealand (Cranfield et al. 2005) there would be few obstacles to establishing a programme to breed resilience to this pathogen. The production of *B. exitiosa* resilient oysters could generate opportunities for *O. chilensis* aquaculture at warm water sites where oyster farming is not presently feasible. Because the mechanisms of oyster immunity to either *Bonamia* species are similar (Martin-Gomez et al. 2012), it is possible that *B. exitiosa* resilient oysters could also have enhanced resilience to *B. ostreae* and could be developed without increasing the risk of spreading *B. ostreae* to uninfected wild populations. It would be worthwhile undertaking molecular analyses on *B. exitiosa* exposed oysters to determine if there are certain genetic markers for this disease resilience, and how they compare to markers found among *B. ostreae*-exposed oysters (as per section 4.2 above).

4.6. Is it expected that a resilience breeding programme could lead to a commercially viable outcome? If yes, what duration of time could be expected before demonstrable recovery?

The TAG was asked to consider whether a *B. ostreae* resilience breeding programme could lead to a commercially viable outcome. In terms of protection and enhancement of wild fisheries, as discussed above, the TAG considers that the challenges and costs of reseeding would be prohibitive and success in the short term unlikely. However, should *B. ostreae* become more widespread and containment no longer the preferred management option, the TAG believes that *B. ostreae* resilient flat oysters could be produced for the aquaculture industry and could support the reestablishment of *O. chilensis* aquaculture. Whether this would be commercially viable is hard to predict. The cost of establishing a breeding program is likely to be greater than $20M. The flat oyster aquaculture industry would need to expand rapidly and reach a size much larger than it was prior to the detection of *B. ostreae* to recoup the investment in a breeding program and/or become economically viable.

Commercial viability of selectively bred shellfish can take a very long time, particularly if a breeding programme's objective is initially research, and if commercial hatchery capacity is lacking (as it currently is in New Zealand for *B. ostreae* infected animals). For instance, the Sydney Rock Oyster program started in 1990 (Nell et al. 2000) and although it is gaining commercial momentum and scope, is still not commercially viable almost 30 years later (Select Oyster Company, *pers. comm.*). However, the Sydney Rock Oyster breeding program is now making substantial gains in disease resilience and growth (Dove et al., 2013a, Dove et al., 2013b). Since 2010 it has transitioned from a mass selected program to a full sibling family program, which has increased the rate of gain for disease resilience and growth, the control for inbreeding, and the maintenance of other commercially viable traits such as condition and shape. While uptake by farmers is increasing it is the lack of capacity among commercial hatcheries to meet demand which is slowing progress. Demand exceeds supply by 600% (Select Oyster Company 2016). There is a reliable wild seed supply of Sydney Rock Oysters so the industry is not dependent on hatchery-reared spat. However, the majority of farmers would prefer to stock selected lines if they could access them.

An alternative model is the Pacific Oyster breeding program in Australia which is approaching commercial viability, as hatchery capacity exceeds demand and farmers are increasingly reliant on OsHV-1 microvariant resistant families. In order to sustain this breeding program, a breeding levy has been applied to sales of Pacific Oyster spat, regardless of whether they are from resistant families or not (ASI). This is because there are no other viable solutions other than development of disease resistant lines to sustain the industry. Consequently, growers who purchase non-resistant lines also pay this levy. Both of these programs are owned and operated by industry-owned companies which were established for the specific purpose of commercialising their breeding programs. A similar commercial management strategy might be necessary should a breeding program be started in New Zealand.

5. Conclusions and recommendations

Current information indicates that *B. ostreae* is contained within the Marlborough Sounds and Big Glory Bay. More will be known once results are returned from the September - October survey. The TAG is of the opinion that preventing the spread of *B. ostreae* to wild fisheries and uninfected coldwater sites suitable for flat oyster aquaculture will provide the greatest benefits to wild populations and the wild harvest industry, with benefits for flat oyster aquaculture both now and in the future.

The increased risk posed to wild *O. chilensis* populations by the remaining *B. ostreae* infected farmed stock in the Marlborough Sounds is real, and remaining oysters should be removed from the water as soon as possible. This action would not spell the end of *O. chilensis* aquaculture in New Zealand or prevent progress towards the development of disease resistant *O. chilensis.* The current situation presents many opportunities to conduct research to support selective breeding of *O. chilensis* family lines with advantageous attributes, including resilience for *B. exitiosa* without the constraints imposed by containment measures for *B. ostreae*. The TAG encourages further research into the genetics and genomics of the oysters and their parasites, and their life-histories from the perspective of restoration and industry needs. Samples from surviving oysters considered putatively resilient should be examined now or stored for future molecular analysis of relevant genetic characteristics. There would be great value in having genomic data available to support any future resilience breeding programme and should *B. ostreae* become widespread, efforts to re-establish flat oyster aquaculture at *B. ostreae* infected locations.

Basic ecological information is lacking including an understanding of the pathology and epidemiology of *B. ostreae* in *O. chilensis* in New Zealand, its life cycle and persistence in the environment, and how these may vary with region and environmental conditions. This information could inform a way forward. Should *B. ostreae* become more widespread in New Zealand and important wild fisheries suffer the expected negative effects of infection, the risks associated with an in-water disease resilience breeding programme would be greatly reduced. In-water disease challenges and/or selective breeding for *B. ostreae* resilience could then be initiated. Such a programme would require significant long term investment.

The TAG acknowledges that this report will be considered by the MPI *Bonamia* 2015 Response Management Team and that the Response Governance has the final decision-making power on the government's response and associated actions. The TAG has no role to play in day-to-day management of MPI's response.

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Appendix 1

TAG Members		
Name	**Organisation**	**Area of expertise**
Dr Phil Ross (TAG Chair)	University of Waikato	Marine community and molecular ecology. Population genetics of endemic toheroa surf clams. Matauranga Maori.
		Australian expert on aquaculture and fisheries biosecurity; research into *Bonamia ostreae*.
Dr Pierre Boudry	Ifremer Research Institute	Expert in genetics/genomics of bivalves. Oyster selective breeding expertise OsHV-1 and *B. ostreae*.
Prof Sarah Culloty	University College Cork	Expert in parasitology / immunology of bivalves. Specific selective breeding expertise for Bonamiosis resilience in European flat oysters.
Keith Michael	NIWA	Fisheries scientist; NZ expert on *B. ostreae.*
Dr Emma Wilkie	Select Oyster Company	Operations Manager- selective breeding programme for Sydney rock oysters for disease resilience, growth rate, & shell shape.
Dr Henry Lane	MPI	*B. ostreae* expert, diagnostics, and forensic genetics.