Recommendation - Risks of bivalve mollusc pathogen emergence in connection with climate change

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Contents

1 SUMMARY – PURPOSE OF THIS DOCUMENT

This recommendation concerns the risk of the emergence of pathogens in bivalve molluscs in relation to climate change. It aims to demonstrate the fragility of shellfish farming in the face of any change in its environment and the need to put appropriate measures in place to protect this important economic sector in Europe. It is becoming apparent that shellfish are in fact highly dependent on the quality of their environment. However, for several years now, European shellfish farming has been facing recurrent episodes of mortality linked to the emergence of new pathogens. These agents, potentially already present in the environment, can become pathogenic following changes in environmental conditions. For several years now, climate change has played a key role in this regard because of its impact, on the marine environment and its coastal ecosystems.

2 INTRODUCTION

Shellfish farming is an essential economic sector in Europe. It represents about 8,500 businesses that employ more than 42,000 people (Arzul et al., 2021) and raise a wide range of shellfish: oysters, mussels, cockles, clams, etc. Europe is ranked between 2nd and 3rd in the world of shellfish producers after the continents of Asia and America. In total, its farmed shellfish production represents 47% in weight and 23% in value of the European aquaculture production (FAO, 2018).

Shellfish production is a response to the need to develop a food industry that is compatible with climate change and fits perfectly into the Green Deal for Europe, because of its socio-economic role in producing wealth and its essential usefulness for the natural environment via the ecosystem services it provides, but it is highly dependent on its environment and its changes. For several years, European shellfish farming has notably been the victim of recurrent episodes of mortality caused by various simultaneous factors: changes in the quality of the environment, changes in the physiology of the shellfish and the appearance of pathogens. In fact, in their environment, shellfish are surrounded by and host communities of micro-organisms, some of which may become pathogenic depending on the environmental conditions of their surroundings. In the last few years, another unknown has also been added to these factors: **the impact of climate change on shellfish farming and in particular on the appearance of emerging pathogens.**

The United Nations Framework Convention on Climate Change (UNFCCC) defines current climate change as "*a change that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods*" (IPCC, 2014a; IPCC, 2014b). The coastal ecosystems are already affected by climate change, which is reflected in warming oceans, their acidification, sea level rise, etc. These risks have a particularly determining impact on the economic sector of aquaculture, but also on fisheries and tourism. They compromise the food safety of seafood for humans and the health of shellfish stocks (IPCC, 2019).

3 DIVERSITY OF BIVALVE PATHOGENS

The World Organisation for Animal Health (WOAH), in its Aquatic Animal Health Code,defines **a disease** as "*an infection, clinical or otherwise, caused by one or more pathogens*" and **a pathogen** as "*a* *micro-organism that causes disease or contributes to its development*" (WOAH(2021). Shellfish pathogens are varied in nature: viruses, bacteria and protozoan parasites.

However, the presence of a pathogen is not systematically synonymous with disease and mortality in shellfish. In fact, pathogens tend to develop and induce mortality when there is an imbalance in the interactions between shellfish, pathogens, the environment and cultural practice (Arzul, 2020).

Depending on their geographical distribution, these pathogens are considered **absent or present in the EU.** Currently, two known protozoan parasites are noted as absent: *Mikrocytos mackini*, presenti in North America since the 1960s and associated in Canada with the mortality of Pacific oysters (*Crassostrea gigas*), and *Perkinsus marinus*, located in particular in the United States, which caused significant mortality of eastern oysters (*Crassostrea virginica*) for the first time in 1946 (Ifremer (LGPMM), 2018).

Other pathogens such as the *Ostreid herpes virus* type 1 (OsHV-1) and the bacterium *Vibrio aestuarianus* are, on the other hand, well established in the EU and responsible for significant mortality, especially in France. Indeed, since the early 1980s, the herpes virus has been regularly associated with episodes of mortality of Pacific oysters (*Crassostrea gigas*) and more particularly spat and juveniles (Ifremer (LGPMM), 2018).

However, from 2008 onwards, the emergence of a particular genotype of the virus (OsHV-1) caused a 60-80% increase in spat mortality (Soletchnik, 2009). In addition to these massive spat mortalities, adult oysters have suffered mortality affecting up to 50% of marketable individuals since 2012. The bacterium *Vibrio aestuarianus* has been systematically detected in oysters during mortality episodes (Garnier et al., 2007).

These examples of mortality episodes prove that the control of shellfish diseases remains complex, that our capacity for dealing with animal health issues is still fragile and requires the intrinsic characteristics of shellfish farming to be taken into account. Molluscs are generally reared in a natural environment and are therefore in direct contact with the environment. This environment is an open one, which in contrast to the terrestrial environment, has no physical barriers, thus allowing the rapid spread and transmission of pathogens.

Moreover, due to their physiology, molluscs do not produce antibodies and have no acquired immunity, which makes the use of vaccines impossible; vaccines and disinfection treatments are not applicable in open environments. They also do not show specific clinical signs, which makes diagnosis difficult. Also, the boundary between wild and farmed animals is not always clear, and wild molluscs are carriers of many potentially pathogenic micro-organisms. Consequently, once a pathogen is established in the environment, its eradication is difficult, if not impossible (Arzul et al., 2021).

It is therefore essential to prevent the introduction and spread of these diseases in order to limit their impact on bivalve molluscs. It also seems essential to prevent the proliferation of diseases through anticipatory regulation of emerging pathogens, for two reasons: **to maintain sustainable shellfish production and to perpetuate the role of sentinel species in the health status of coastal ecosystems** (Arzul, 2020).

4. EMERGING PATHOGENS AND DISEASES AFFECTING SHELLFISH FARMING

WOAH (2021) defines **an emerging disease** as any "*disease, other than those listed [...], that has a significant impact on animal or human health and results from:*

a. *The modification of a known pathogen or its spread to a new geographical area or a new species, or*
b. *The presence of a new agent recognised or suspected of being a pathogen".*

The EU also characterises **the notion of an emerging illness** in its regulation (EU) 2016/429 in Article 6:

"*[...] 2. A disease not appearing among the listed diseases is considered to be an emerging disease [...] when it is likely to meet the criteria set out in Artcile 5, paragraph 3, and that it:*

a) results from the evolution or modification of an existing pathogen;

b) is a known illness spreading to a new geographical area, a new species or a new population;

c) is diagnosed for the first time in the EU; or

d) is caused by an unrecognised or previously unrecognised pathogen."

There are many criteria that can favour the emergence of pathogens in shellfish farming. During the farming process, shellfish are subject to numerous changes in the production areas. They can therefore carry invasive species or pathogens during these movements.

Moreover, shellfish are cold-blooded animals, very sensitive to stress factors often produced outside their natural range, and living in an environment naturally rich in pathogens. These pathogens mainly develop within wild shellfish populations and then contaminate one or more farming areas. In general, any change in the environment, farming practices or the physiology of the shellfish can lead to the emergence of a pathogen that causes mortality. Indeed, an epidemic may be favoured by changed environmental conditions which would increase the prevalence and virulence of an existing disease or facilitate the emergence of a new one (Krause, 1998; Harvell et al., 1999; Burge et al., 2014).

Finally, the lack of data on pathogens and their hosts makes it difficult to make diagnoses, which are mainly centred on known or regulated diseases. Today, we note that **few inventories of pathogens and their hosts present on national territories exist and that current surveillance and management measures remain insufficient.**

5. CLIMATE CHANGE AND SHELLFISH FARMING

The marine environment and associated economic activities, such as shellfish farming, are already being affected by the effects of climate change. Environmental changes affect the health and productivity of marine ecosystems on large spatial and temporal scales (Harvell et al., 1999).

Indeed, global warming could induce changes in the biology of marine populations making them more susceptible to disease. In particular, **ocean warming** has many consequences for disease dynamics. In the United States, the last 25 years have seen a warming of winter temperatures on the East coast which has facilitated the spread of *Perkinsus marinus* and *Haplosporidium nelsoni* (also known as MXS) (Cook et al., 1998; Dittman et al.). Warmer winters decrease parasite mortality and result in heavier MSX infections in oysters (Harvell et al., 1999). Yet future emission scenarios predict that the surface ocean temperature is expected to increase by a further 0.6-2.0°C in the top 100 metres by 2100 (IPCC, 2013) knowing that since 1970 the global ocean has warmed (0.11°C per decade) and has absorbed more than 90% of the excess heat from the climate.

Ocean acidification (OA) leads to a decrease in the concentration of carbonate ions (CO32-), a constituent of calcium carbonate (CaCO3), which is essential for the manufacture of mollusc shells (Gazeau et al., 2007). A growing number of publications describe the negative effects of OA on the development, growth, calcification, disease susceptibility and survival of many species of molluscs. The direct effects of OA on shellfish farming were already observed almost ten years ago on a local scale on the West coast of the United States (Barton et al., 2015). Scientists and shellfish farmers have since identified a strong correlation between water acidity and oyster larval mortality (Barton et al., 2015)and developed local adaptive strategies (Barton et al., 2015; Ekstrom et al., 2015).

One can also note other consequences of climate change, the effects of which on shellfish farming are still poorly documented, but already reveal large-scale impacts on marine ecosystems: the stratification of the oceans, loss of oxygen at the surface with changes in ventilation and biogeochemistry, alteration in net primary production, change in geographical ranges and seasonal activities of marine species (IPCC, 2019).

In general, climate change and human activities have accelerated (Harvell et al., 1999; Burge et al., 2014):

- increased transport of species around the world, exposing some marine populations to new pathogens. It has been suggested that the most important bivalve mollusc mortalities result from transfers of contaminated stocks.
- the weakening of farmed animals that expend energy to acclimatise or adapt to these new conditions.

However, shellfish appear to have **some capacities to adapt to climate change** according to recent discoveries in genomics. Bivalves are believed to possess tolerance and resilience to cocktails of environmental stresses and traits of phenotypic plasticity, ensuring genetic adaptation to their habitats. These characteristics will be key in helping shellfish businesses to be "climate resilient" (Byrne et al., 2020) and resistant to new pathogens (Yu and Guo, 2006; Lallias et al., 2009; Sauvage et al., 2010).

Indeed, some shellfish species - more specifically some oyster species - show a high polymorphy and a richness of repetitive sequences, allowing them to develop a large phenotypic variation (Zhang et al., 2012). Although we may be tempted to minimise the role of immunity in these invertebrates, recent advances have also led to a better understanding of the genomes of the hosts and their parasites. Thus, several studies have revealed surprisingly sophisticated innate immune systems in molluscs (Guo and Ford, 2016). The main pathways of innate immunity are present in molluscs via numerous extended receptors, regulators and immune system effectors. Extended gene families provide great diversity and complexity in the innate immune response, which may be key to mollusc defence against various pathogens in the absence of adaptive immunity (Guo and Ford, 2016).

However, the gene base of resistance to diseases or environmental stress for most species of molluscs of commercial interest worldwide (and especially in the EU) remains largely unknown (Gómez-Chiarri et al., 2015). Hence, the study of the transcriptomes of molluscs of interest and their parasites, as well as the advancement of knowledge on phenotypic adjustment and/or genetic selection, taking into account the complex interactions between plasticity and adaptation, would be avenues to be explored to improve our understanding of genetic variation in parasite virulence and host disease resistance (Guo and Ford, 2016; Byrne et al., 2020).

6. EXAMPLES OF EMERGING RISK MANAGEMENT MEASURES IN PLACE AND SUGGESTIONS FOR IMPROVING RESILIENCE, RESISTANCE AND TOLERANCE

In France, the emergence of bivalve pathogens is monitored through the REPAMO network (REseau de surveillance des PAthologies des MOllusques marins /Marine Mollusc Disease Surveillance Network). Created in 1992, this network performs a regulatory and public service mission for the Ministry of Agriculture and Food, which has recently been delegated to the shellfish farming and professional fishing inter-professional associations. The objective of REPAMO is to detect and identify as early as possible the regulated and/or emerging infectious pathogens associated with mortality events in wild and farmed marine molluscs. It is a passive event-based surveillance based on mandatory reporting by professionals of any abnormal increase in mortality.

Unfortunately, this surveillance network requires improvement and only partially responds to the issue of combating the introduction/emergence and spread of emerging pathogens. In fact, this network only targets the pathogens listed and known from the histological analysis of shellfish. However, this method is not very specific to pathogens other than parasites and the results can only be delivered within a minimum of ten days. This long delay makes it impossible to detect emerging pathogens and to implement effective management measures. Finally, it does not include any monitoring of the environmental parameters.

Other initiatives for monitoring emerging pathogens exist in Europe, such as the work of the Native Oyster Restoration Alliance (NORA) European network of professionals, focusing on the development of policies that recognise the importance of the habitat created by the native European oyster, *Ostrea edulis*, and the benefits of restoring it throughout its historical range (Pogoda et al., 2019). The NORA network proposes biosecurity guidelines for the restoration of native oysters in Europe, concentrating on different aspects, such as oyster spat production, but especially on preventing the spread of *Bonamia* and other marine pathogens, diseases and invasive species. The aim is to take into account all known diseases and to anticipate the appearance of unexpected diseases or invasive species, potentially induced by climate change and warm sea temperatures (Pogoda et al., 2020).

Finally, several scientific reports putting forward recommendations to improve practices for better resistance, resilience or tolerance to emerging pathogens have been published recent years. Among them, the project VIVALDI which aims to improve the durability and competitivity of the European shellfish farming sector, which has been hit by a growing number of cases of mortality cases in recent years. To this end, tools and strategies designed to better prevent and mitigate the impact of bivalve mollusc diseases were developed from 2016 to 2020. Among the set of recommendations proposed, we note in particular the one concerning the development of breeding programmes to improve disease resistance by following good production practices (Arzul et al., 2021).

On the other hand, several works have noted the importance setting out a single definition of the terms **"resistance", "resilience" and "tolerance"** for the implementation of regulatory mechanisms that underpin marine management (Holbrook et al., 2021). So, in order to avoid any blockages during future discussions on the development of necessary policies and to avoid the spread of disease to new locations and populations, further work appears necessary to resolve the practical uncertainty associated with the definition and application of these terms (Holbrook et al., 2021).

The involvement and participation of all stakeholders (competent authorities, inter-professional and professional bodies, research bodies) would clearly be a *sine qua non* condition for the success of these projects. Communication channels between all the stakeholders must therefore be clearly defined (Arzul et al., 2021).

7. CONCLUSION

Despite much research, the evolution of marine pathogens and their ecological impact remains uncertain (Harvell et al., 1999). In contrast, there is little research and a lack of knowledge on climate change and its impact on shellfish farming and its known and emerging pathogens.

However, the rare studies that have been carried out have been on a number of negative economic impacts of climate change, either in terms of net current value, income, consumer welfare or the nutritional value of products (Falkenberg and Tubb, 2017; Narita and Rehdanz, 2017; Froehlich et al., 2018). The annual impact of OA on European shellfish production has been estimated to be more than USD 1 billion in 2100, unevenly distributed across countries (Narita and Rehdanz, 2017). On a broader front, climate change and more particularly OA will lead to variations in the goods and services provided by shellfish ecosystems and by shellfish farming (Le Bihan-Charpentier, 2015; Smaal et al., 2019).

It seems essential therefore to **work in greater depth on these two closely related subjects: the emergence of pathogens in bivalve molluscs and the impact of climate change on shellfish farming**.

8. RECOMMENDATIONS OF THE AAC

In conclusion the Aquaculture Advisory Council (AAC) recommends that the **European Commission**:

- Protects shellfish water quality by ensuring good shellfish status as described in the AAC recommendation, available HERE, relating to the protection of the quality of shellfish waters (April 2020);

- Assesses the impact of climate change on shellfish farming in the long term, particularly through the development of climate and socio-economic models;
- Provides funding for animal health monitoring of shellfish stocks and for improving shellfish water quality directly linked to good health of the shellfish;
- Includes these research needs in the vision and work priorities of EATIP (European Aquaculture Technology and Innovation Platform);
- Adds a specific page for shellfish farming and animal health on the future European Commission website, dedicated to aquaculture to share any information related to the following areas: biodiversity monitoring, climate change, animal health surveillance and emerging pathogens, sharing of good animal health practices, etc.
- Identifies and strengthens communication channels, exchange information on these subjects and integrate work on the definition of appropriate regulatory animal health terms between European actors (Member States, competent authorities, researchers, professional representatives) but also with international stakeholders.

The Aquaculture Advisory Council also recommends that **Member States:**

- Defend the good quality of shellfish waters by enforcing existing regulations and combating any new pollution by targeting the sources of contamination and not the shellfish farmers;
- Include shellfish farmers in water quality assessment processes;
- Improve the detection and identification of emerging pathogens: by studying the diversity of known pathogens, the evolution of environmental conditions, the different existing reservoirs (sediments, water, plankton, etc.), by developing rapid, multi-pathogen detection tools adapted to the needs of professionals (passive sensors, multi-primer PCR, DNA sequencing, etc.);
- Adapting animal health surveillance strategies to climate change and emerging pathogens: programmed surveillance, monitoring of environmental parameters, management measures, etc.;
- Improve the defence mechanisms of hatchery shellfish by optimising genetic selection programmes through the study of pathogen virulence, identification of markers associated with better survival, stimulating immunity and measuring defence mechanisms;
- Strengthen communication between the competent authorities responsible for water quality and coastal areas, research and the shellfish industry;
- Strengthen the link between research and professionals by creating applied research programmes (cultivation practices, environmental impacts, etc.) in line with the needs of the profession and offering tools and applications adapted to these needs;
- Rely on the EATIP's mirror platform and integrate these recommendations into the work programmes.

REFERENCES

Anderson, R. M. (1998) Analytic theory of epidemics, p. 23-50. In R. M. Krause (ed.), Emerging infections. Academic Press, New York, N.Y.

Arzul I (2020) Pourquoi les huîtres sont-elles de plus en plus souvent malades ? The Conversation, http://theconversation.com/pourquoi-les-huitres-sont-elles-de-plus-en-plus-souvent-malades-152005

Arzul I, Furones D, Cheslett D., Gennari L., Delangle E., Enez F., Lupo C., Mortensen S., Pernet F. et Peeler E. (2021) Manuel de gestion des maladies des mollusques bivalves et de biosécurité - Projet H2020 VIVALDI -p.44.

Barton A, Waldbusser GG, Feely RA, Weisberg SB, Newton JA, Hales B, Cudd S, Eudeline B, Langdon CJ, Jefferds I, et al (2015) Impacts of Coastal Acidification on the Pacific Northwest Shellfish Industry and Adaptation Strategies Implemented in Response. Oceanography **28**: 146–159

Burge CA, Mark Eakin C, Friedman CS, Froelich B, Hershberger PK, Hofmann EE, Petes LE, Prager KC, Weil E, Willis BL, et al (2014) Climate Change Influences on Marine Infectious Diseases: Implications for Management and Society. Annu Rev Mar Sci **6**: 249–277

Byrne M, Foo SA, Ross PM, Putnam HM (2020) Limitations of cross- and multigenerational plasticity for marine invertebrates faced with global climate change. Global Change Biology **26**: 80–102

Cook T, Folli M, Klinck J, Ford S, Miller J (1998) The Relationship Between Increasing Sea-surface Temperature and the Northward Spread ofPerkinsus marinus(Dermo) Disease Epizootics in Oysters. Estuarine, Coastal and Shelf Science **46**: 587–597

Dittman DE, Ford SE, Padillai DK EFFECTSOF PERKINSUSMARINUS ON REPRODUCTIONAND CONDITION OF THE EASTERN OYSTER,CRASSOSTREAVIRGINICA.DEPEND ON TIMING. 11

Ekstrom JA, Suatoni L, Cooley SR, Pendleton LH, Waldbusser GG, Cinner JE, Ritter J, Langdon C, van Hooidonk R, Gledhill D, et al (2015) Vulnerability and adaptation of US shellfisheries to ocean acidification. Nature Clim Change **5**: 207–214

Falkenberg LJ, Tubb A (2017) Economic effects of ocean acidification: Publication patterns and directions for future research. Ambio **46**: 543–553

FAO (2018) FIGIS Fisheries Statistics - Aquaculture. https://www.fao.org/figis/servlet/TabSelector

Froehlich HE, Gentry RR, Halpern BS (2018) Global change in marine aquaculture production potential under climate change. Nat Ecol Evol **2**: 1745–1750

Garnier M, Labreuche Y, Garcia C, Robert M, Nicolas J-L (2007) Evidence for the Involvement of Pathogenic Bacteria in Summer Mortalities of the Pacific Oyster Crassostrea gigas. Microb Ecol **53**: 187–196

Gazeau F, Quiblier C, Jansen JM, Gattuso J-P, Middelburg JJ, Heip CHR (2007) Impact of elevated CO2 on shellfish calcification. Geophysical Research Letters. doi: 10.1029/2006GL028554

Gómez-Chiarri M, Warren WC, Guo X, Proestou D (2015) Developing tools for the study of molluscan immunity: The sequencing of the genome of the eastern oyster, Crassostrea virginica. Fish & Shellfish Immunology **46**: 2–4

Guo X, Ford SE (2016) Infectious diseases of marine molluscs and host responses as revealed by genomic tools. Philosophical Transactions of the Royal Society B: Biological Sciences **371**: 20150206

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofmann EE, Lipp EK, Osterhaus ADME, Overstreet RM, et al (1999) Emerging Marine Diseases--Climate Links and Anthropogenic Factors. Science **285**: 1505–1510

Holbrook Z, Bean TP, Lynch SA, Hauton C (2021) What do the terms resistance, tolerance, and resilience mean in the case of Ostrea edulis infected by the haplosporidian parasite Bonamia ostreae. Journal of Invertebrate Pathology **182**: 107579

Ifremer, Laboratoire Génétique et Pathologie des Mollusques Marins (LGPMM), Ifremer, Direction de la communication (DCOM) (2018) Les agents pathogènes affectant les mollusques marins. Fiches pédagogiques.

IPCC (2014a) AR5 Synthesis Report: Climate Change 2014 — IPCC.

IPCC (2014b) AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability.

IPCC (2019) Special Report on the Ocean and Cryosphere in a Changing Climate —.

IPCC (2013) AR5 Climate Change 2013: The Physical Science Basis.

Krause RM (1998) 1 Introduction to emerging infectious diseases; stemming the tide. *In* RM Krause, ed, Biomedical Research Reports. Academic Press, pp 1–22

Lallias D, Gomez-Raya L, Haley CS, Arzul I, Heurtebise S, Beaumont AR, Boudry P, Lapègue S (2009) Combining Two-Stage Testing and Interval Mapping Strategies to Detect QTL for Resistance to Bonamiosis in the European Flat Oyster Ostrea edulis. Mar Biotechnol **11**: 570

Le Bihan-Charpentier V (2015) Analyse économique du risque en conchyliculture. These de doctorat. Nantes

Narita D, Rehdanz K (2017) Economic impact of ocean acidification on shellfish production in Europe. Journal of Environmental Planning and Management **60**: 500–518

Pogoda B, Boudry P, Bromley C, Cameron TC, Colsoul B, Donnan D, Hancock B, Hugh-Jones T, Preston J, Sanderson WG, et al (2020) NORA moving forward: Developing an oyster restoration network in Europe to support the Berlin Oyster Recommendation. Aquatic Conservation: Marine and Freshwater Ecosystems **30**: 2031–2037

Pogoda B, Brown J, Hancock B, Preston J, Pouvreau S, Kamermans P, Sanderson W, Nordheim H von (2019) The Native Oyster Restoration Alliance (NORA) and the Berlin Oyster Recommendation: bringing back a key ecosystem engineer by developing and supporting best practice in Europe. Aquat Living Resour **32**: 13

Sauvage C, Boudry P, De Koning D-J, Haley CS, Heurtebise S, Lapègue S (2010) QTL for resistance to summer mortality and OsHV-1 load in the Pacific oyster (Crassostrea gigas). Animal Genetics **41**: 390–399

Smaal AC, Ferreira JG, Grant J, Petersen JK, Strand Ø, eds (2019) Goods and Services of Marine Bivalves. doi: 10.1007/978-3-319-96776-9

Soletchnik P (2009) Mortalités exceptionnelles d'huîtres creuses dans les Pertuis Charentais. Synthèse des résultats 2008-2009.

Yu Z, Guo X (2006) Identification and mapping of disease-resistance QTLs in the eastern oyster, Crassostrea virginica Gmelin. Aquaculture **254**: 160–170

Zhang G, Fang X, Guo X, Li L, Luo R, Xu F, Yang P, Zhang L, Wang X, Qi H, et al (2012) The oyster genome reveals stress adaptation and complexity of shell formation. Nature **490**: 49–54

(2021) Code sanitaire pour les animaux aquatiques (2021). OIE - Organisation Mondiale de la Santé Animale

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