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Quo Vadimus

Welfare of aquatic animals: where things are, where they are going, and what it means for research, aquaculture, recreational angling, and commercial fishing

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We revisit the evidence attributing sentience-pain-suffering to aquatic animals. The objective is to inform readers of the current state of affairs, to direct attention to where research is needed, and to identify "wicked" questions that are difficult to resolve unequivocally. By separating the ethical from the scientific debate, applying organized skepticism to the latter, and taking a pragmatic approach that does not depend on resolving the "wicked" questions, we hope to focus and strengthen research on aquatic animal welfare. A second but closely-related objective is to briefly summarize the research used to support the regulations governing the welfare of aquatic animals, particularly its limitations. If you interact with aquatic animals, these regulations already affect you. If the regulatory environment continues on its current trajectory (adding more aquatic animal taxa to those already regulated), activity in some sectors could be severely restricted, even banned. There are surely some lively debates and tough choices ahead. In the end, extending legal protection to aquatic animals is a societal choice, but that

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choice should not be ascribed to strong support from a body of research that does not yet exist, and may never exist, and the consequences of making that decision must be carefully weighed.

Keywords: Sentience, consciousness, pain, suffering, euthanasia, slaughter, animal-based measures, precautionary principle, 3 Rs, humane end points, European Directive 2010/63/EU.

> The improver of natural knowledge absolutely refuses to acknowledge authority, as such. For him, scepticism is the highest of duties; blind faith the one unpardonable sin. And it cannot be otherwise, for every great advance in natural knowledge has involved the absolute rejection of authority, the cherishing of the keenest scepticism, the annihilation of the spirit of blind faith; and the most ardent votary of science holds his firmest convictions, not because the men he most venerates hold them; not because their verity is testified by portents and wonders; but because his experience teaches him that whenever he chooses to bring these convictions into contact with their primary source, Nature—whenever he thinks fit to test them by appealing to experiment and to observation—Nature will confirm them. The man of science has learned to believe in justification, not by faith, but by verification (T.H. Huxley, 1866)

Introduction

Diggles's (2019) review of the science available to inform aquatic crustacean welfare appears in this issue of the *ICES Journal of Marine Science*. Beyond the many technical concerns, his review raises numerous issues about the path that research on aquatic animal welfare is on, some of which have been raised before (e.g. Arlinghaus *et al.*, 2007a, 2009, 2012; Rose, 2007; Arlinghaus and Schwab, 2011; Browman and Skiftesvik, 2011; Rose *et al.*, 2014; Key, 2015). Since many of the issues raised by Diggles (2019) can be applied to any aquatic "lower" vertebrate or invertebrate, the publication of his review provides an opportunity to revisit the evidence attributing sentience-pain-suffering to aquatic animals and, as a consequence, the ethical and legal obligations to protect their welfare. The objective is to inform readers of the current state of affairs, to direct attention to where research is needed, and to identify those "wicked" questions that are difficult to resolve unequivocally. Importantly, some of the issues that are under debate are entirely ethical and, as such, fall outside the realms of scientific discourse. By separating the ethical from the scientific debate, applying organized scepticism to the latter, and taking a pragmatic approach that does not depend on resolving the "wicked" questions, we hope to focus and strengthen research on aquatic animal welfare.

A second, but closely related objective, is to briefly summarize the research used to support the regulations governing the welfare of aquatic animals, particularly its limitations. If you are a researcher, fisher, resource/fisheries manager or regulator, aquaculturist/fish farmer, angler, zookeeper or aquarist, these regulations already affect you. If the regulatory environment continues on its current trajectory (adding more aquatic animal taxa to those already regulated), activity in some sectors could be severely restricted, even banned.

Where things are

We will use Europe as a case study, although the situation is similar in many of the Organisation for Economic Cooperation and Development's 34 member states.

The European Directive 2010/63/EU (European Parliament, 2010) on the protection of animals used for scientific purposes includes marine vertebrates and cephalopods (>700 extant species of cuttlefish, squid, octopus, and nautiloids) (Smith *et al.*, 2013). The Directive covers cephalopods from hatching; eggs are not protected. Independently feeding larval vertebrates (including fish), and foetal mammals from the last third of development, are also protected. Some countries had already extended protection to decapods and honeybees before the 2010 Directive was adopted, through national legislation regulating the use of animals in research (Table 1).

The Directive only protects vertebrates and cephalopods used in scientific procedures. It does not apply to commercial or subsistence capture or recreational fishing, aquaculture or public or private aquaria (ornamental fish keeping) unless research is being carried out in association with those activities. However, the reasoning that underlies the EU Directive is similar to that of some national welfare legislation, which has, in the past, also been applied to commercial and recreational fishing and to aquaculture (Arlinghaus *et al.*, 2009, 2012). Thus, the basis for, and details of, the EU Directive on animal experimentation provides an important context for the material that follows. Specifically, it is important to be aware of the following:

- The European regulations on animal use in research and in farming/aquaculture are related, and the underlying principles of both are analogous. Basically, when animals (sentient or not) are "in our care" we have an ethical obligation towards them; that is, to treat them "humanely". The current EU regulations, and many national regulations, do not yet apply to free-living animals in the wild, as they are not "in our care".
- The current regulations only apply to animals that are classified as sentient. However, sentient is not clearly defined in the EU regulations. How it is decided whether any given taxon is sentient is even fuzzier, although it typically involves measures of complexity in neuroanatomy, memory, and behaviour. Nonetheless, there are calls to accept the premise that all animals are sentient (Le Neindre *et al.*, 2017).
- The capacity of an animal to experience pain and suffering forms the basis of the current legal regulations governing how its welfare is handled and how it is euthanized or slaughtered. Taxa classified as sentient are considered able to experience pain and suffering. Thus, research on aquatic animal welfare that is intended to inform the regulatory process about what particular animal group or species to include in the regulations (or not) must provide evidence for or against the existence of sentience-pain-suffering.
- Sentient animals that are "in our care" must be provided with comfortable conditions that optimize their health and welfare,

Table 1. Legislation extending protections to invertebrates used in research.

Country	Invertebrate group	Regulation
Australia	Cephalopods	National Health and MedicalResearch Council's Australian code for the care and use of animals for scientific purposes, 8th edition (2013)
Canada	Cephalopods and "some other higher invertebrates"	Canadian Council on Animal Care (1991)
European Union	Cephalopods	European Directive 2010/63/EU
New Zealand	Octopus, squid, crab, lobster, crayfish	Animal Welfare Act (1999)
Norway	Squid, octopus, decapod crustaceans, honeybees	Norwegian Animal Welfare Act (2009)
Switzerland	Cephalopods, decapod crustaceans	Swiss Animal Welfare Act (2008)

Typically, protection is only accorded to animals used in scientific procedures and does not apply to aquaculture or public aquaria, unless research is being carried out in those facilities. Information was collated from the regulations cited and from Guillen (2017).

and be euthanized or slaughtered as quickly and painlessly as possible. In practice, this means that the animal must be rendered unconscious and insensible, eliminating the possibility for pain, distress, or suffering until the moment that it is killed [European Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing]. Under the current regulations (that stipulate that all vertebrate animals are sentient), the method and duration of the euthanasia or slaughter process is less critical for animals that are not sentient and cannot (by definition) experience pain or suffering. On the other hand, to maintain the health of animals in captivity, the need for/benefit of providing comfortable conditions and an appropriate method of euthanasia are the same, regardless of whether or not the animal is sentient. This has been referred to as the pragmatic approach to aquatic animal welfare (Arlinghaus *et al.*, 2009), and contrasts with the pain-centred approach that is based on the presumption that the animal is sentient and experiences pain and suffering (e.g. Huntingford *et al.*, 2006, 2007).

- Animals must not be used at all without justification because a fundamental ethical respect for life dictates that careless or indiscriminate use of any animal is not acceptable.
- The numbers of animals used in research should be kept to a minimum, following the principles of replacement, reduction, and refinement (the three Rs) (Tannenbaum and Bennett, 2015; Holly *et al.*, 2016).

All of the above contextualizes the driver for, and importance of, the debate—scientific, ethical, and legal—surrounding whether fish and other aquatic animals are sentient and have the capacity to experience pain and suffering. It is also a strong motivator for research on these questions and, very importantly, for the manner in which that research is interpreted and applied, particularly the terminology used (e.g. pain vs. nociception). We will limit our coverage to the scientific debate, to which we will apply the principle of organized scepticism. This principle is a norm of science (Huxley, 1866; May, 2011) and not a form of denialism, although it can be misconstrued/misrepresented as such (e.g. Sneddon *et al.* 2018).

While the ethical debate over which aquatic animals to include in the regulations is ideally informed by science, that debate can easily be conflated with the scientific discourse over the relevance and veracity of the research available to inform the question. Such a conflation of the scientific with the ethical is common, including in the scientific literature on aquatic animal welfare (reviewed by Rose, 2007; Arlinghaus *et al.*, 2009; Browman and Skiftesvik, 2011). In our view, this is counter-productive and must be scrupulously avoided (Derbyshire and Bagshaw, 2008). Failure to be disciplined about this risks being perceived as advocacy for or against a particular policy direction. We acknowledge that there will always be at least some element of personal values or preferences involved, but scientists would be well-advised to separate the natural science questions surrounding sentience and pain from its ethical implications, and to avoid mixing these in scientific articles or in the mass media.

The question of whether fish are sentient, and are able to experience pain and suffering, can be traced back to the late nineteenth century (Strange, 1870; Collier, 1889). More recently, the question of whether fish can experience pain was reviewed by Rose (2002), who concluded that it is unlikely in teleosts and does not exist in elasmobranchs (given their lack of nociceptors), and Sneddon *et al.* (2003) who concluded the opposite based on experiments with rainbow trout (*Oncorhynchus mykiss*). This was followed by several studies presenting what is typically interpreted (by the authors) as evidence that is "consistent with" the conclusion that fish experience pain (reviewed by Huntingford *et al.*, 2006; EFSA, 2009; Braithwaite, 2010; Brown, 2015; Sneddon *et al.*, 2014; Sneddon, 2018; Sneddon *et al.*, 2018). However, numerous shortcomings in the definition of pain, as well as in the experimental design and data analysis of these studies have been identified, and the interpretations are often based on arguments—constructed to support the conclusion that the results are "consistent with" pain—presented with little or no mention of the many possible, and equally plausible, alternative interpretations (see Rose 2003, 2007; Rose *et al.*, 2014; Key, 2015, 2016a; Sullivan and Derbyshire, 2015; Derbyshire, 2016; Stevens *et al.*, 2016; Diggles *et al.*, 2017; Key *et al.*, 2017; Diggles, 2019 for detailed critiques; Box 1; and Gould, 1978, and Boutron and Ravaud, 2018, for general treatments of the issue of over-interpretation of results).

With the disclaimer that this is a simplification, the scientific debate distils down to whether any given animal group or species has the anatomical and neurophysiological underpinnings [nociceptors (= trauma receptors) and a central nervous system, including a brain, with structural organization and operational capacity to accomplish the sophisticated processing] to support sentience-pain-suffering as an emotional experience, and exhibit behaviours consistent with that (Box 1). Marshalling clear and unequivocal evidence about either of these is what can be considered a "wicked" problem because consciousness is not well understood, even in humans, and it is a prerequisite for the ability of an organism to experience pain and suffering (Box 1). Gutfreund (2017) concludes, "...the question of animal consciousness is, in theory, tractable, but that a full understanding of the neural basis

Box 1. Which aquatic animals experience pain?

The basic neurological structures and systems that underlie the perception of painful stimuli in humans are known. These include two types of injury-detecting receptors (A-delta and C fibre receptors), neural pathways from peripheral nerves through the spinal cord and brainstem and, ultimately, specialized regions of the cortex. These cortical regions are also involved in the generation of consciousness, an essential condition for pain (Merskey, 1991; Derbyshire, 1999). The International Association for the Study of Pain (IASP) states that "activity induced in the nociceptor and nociceptive pathways by a noxious stimulus is not pain, which is always a psychological state". Fish lack key components of the consciousness-mediating systems and have no plausible and known substitute systems (Rose, 2002; Key, 2015). In addition, the few teleost fish that have been studied have A-delta fibre nociceptors (Sneddon 2003), which in humans signal localized noxious stimuli. All fish studied to date have very few C fibre nociceptors, which are extremely abundant in humans and, in concert with the cortex, evoke sustained, excruciating pain. Elasmobranchs (sharks and rays) studied to date lack all types of nociceptors, yet they display a typical behavioural reaction to noxious stimuli and fishing (i.e. an autonomic and nonconscious escape response) that is similar to that of teleosts. Although these observations make the prospect that fish could experience pain as a psychological state (as in humans or mammals) highly improbable, a series of behavioural studies, mostly involving injection of chemical irritants into the jaws of freshwater salmonids, have served as the principal basis for concluding that fish can experience pain (reviewed in Braithwaite, 2010; Sneddon *et al.*, 2014). Critical examination of these studies has revealed deficiencies in the methods used for pain identification, particularly for distinguishing unconscious detection of injurious stimuli (nociception) from conscious pain. Results were also frequently over and/or misinterpreted (see Rose *et al.*, 2014; Derbyshire, 2016; Stevens *et al.*, 2016; Diggles *et al.*, 2017; Key *et al.*, 2017; and Gould, 1978 and Boutron and Ravaud, 2018 for general treatments of the issue of over-interpretation of results), and have in some cases proven to be irreplicable (Newby and Stevens, 2008; 2009; Puri and Faulkes, 2010). In contrast, there is abundant evidence that surgical implantation of tags and various other injurious events have little or no effect on feeding, migration, spawning, or survival of free-living fish (see Rose *et al.*, 2014; Pullen *et al.* 2017, and references cited therein). Overall, the behavioural and neurobiological evidence shows that fish responses to nociceptive stimuli are limited and that fish are unlikely to experience pain in a manner consistent with the IASP definition.

As pointed out by Diggles (2019), all of the above applies equally and analogously to any other aquatic animal group ("lower" vertebrates and invertebrates). Diggles (2019) states, ". . .as taxa further and further away in evolutionary and morphological terms from humans are considered, it is reasonable to ask how analogous their experiences to noxious stimuli are to the human experience, and therefore how relevant phylogenetically retrospective use of the word 'pain' becomes (Derbyshire, 2016; Diggles, 2016a). For this reason, some scientists consider it inappropriate (or even mischievous) to use the word 'pain' to describe behaviours and experiences of fish (and crustaceans), as this is essentially a form of anthropomorphism (Rose, 2007; Rose *et al.*, 2014) that invites false equivalence between the experience of those animals and that of human pain (Derbyshire, 2016)".

of human consciousness must first be obtained. I believe it is time to admit that until then we cannot answer the question of animal consciousness." (see Dawkins, 2012; Mashour, 2018 for detailed accounts). In the opening editorial of the journal *Neuroscience of Consciousness*, the aim of which is to publish papers ". . .on the biological basis of consciousness. . .", the editors state, "A challenge facing consciousness science is the lack of a consensual definition for consciousness." (Seth *et al.*, 2015). When it comes to fish, Allen (2013) concludes that, ". . .given the diversity of fish species and the limited extent to which they have been studied, blanket statements about fish cognition and consciousness are not responsible." Thus, we argue that it is premature to base legally binding regulations on a concept that researchers cannot clearly define and do not understand, even in humans.

The central argument against sentience-pain-suffering in aquatic animals is based on long-existing knowledge of animal behaviour and basic principles of neurobiology, phylogenetics, and evolutionary parallelisms and homologies (possible functional equivalence or lack thereof), while also accepting their limitations, leading to the conclusion that it is unlikely in fish and invertebrates (Rose *et al.*, 2014; Key, 2015; Diggles, 2019; see Box 1 for further details). The counter-argument distils down to a suggestion that a given animal group or species possesses some other neuroanatomical structures and physiological responses that, through functional equivalence, may endow it with sentience and the ability to experience pain and suffering (e.g. Braithwaite, 2010; Brown, 2015; Woodruff, 2017). Seemingly complex behavioural responses to noxious stimuli, some of which can be alleviated by pain killers that are effective in humans, are typically interpreted as being "consistent with" sentience and the ability to experience pain and suffering (e.g. Huntingford *et al*, 2006; Braithwaite, 2010; Brown, 2015; Sneddon *et al.*, 2014). Consequently, some argue that to avoid the risk that we are causing suffering in untold numbers of animals, we should accept this as a sufficient basis to apply the precautionary principle and extend aquatic animals the benefit of the doubt, according them the same protections as other sentient animals (e.g. Huntingford *et al.*, 2006; Sneddon, 2006; Braithwaite, 2010; Brown, 2015; Birch, 2017; Knutsson and Munthe, 2017). Importantly, the precautionary principle/benefit of the doubt approach reverses the burden of proof from a requirement to prove that these animals are conscious and experience pain and suffering, to proving that

they are not and do not (Key, 2016b). Since the precautionary principle/benefit of the doubt approach cannot be falsified, it is an untestable hypothesis which, by definition, is not scientific (Key *et al.*, 2017). As such, it seems imprudent to apply it as the basis for regulations with sweeping implications because it can only be reversed if convincing evidence—which is essentially impossible to produce—is brought forward. In such situations, and particularly when so much is at stake (see below), we argue for a pragmatic, pro-active problem-solving approach in which information on the well-being of fish and other aquatic animals is collected using objective indicators of stress, health status, and behaviour that are situation and species-specific and make no assumption about sentience, pain, or suffering (see Arlinghaus *et al.*, 2009; Diggles *et al.*, 2011 for detailed accounts). Applying the precautionary principle and presuming sentience, pain, and suffering when it might not exist, could result in the development and application of measures that are not well matched to the particular animal and, thereby, possibly reduce rather than increase its welfare. Alternately, the research community could conclude that these "wicked" questions cannot be answered by science as we currently know it, and that the pragmatic approach is inadequate/insufficient, which would make the debate exclusively ethical.

In an important contribution to the debate about animal sentience and its connection to welfare, Dawkins (2012, 2017) concluded—as do Gutfreund (2017) and Mashour (2018) —that the question of consciousness has not yet been settled for any animal and is unlikely to be resolved for some time. Dawkins argued that animal welfare considerations do not/should not hinge on whether a given animal is conscious. One particularly important ramification of Dawkins' view is that, if a given taxon or species were convincingly shown to be devoid of consciousness, that fact must not diminish the importance of welfare considerations. We consider this position equivalent to/consistent with the pragmatic approach to aquatic animal welfare described above.

Where are things going?

As Diggles (2019) points out, applying the precautionary principle/benefit of the doubt approach, while at the same time defining pain using behavioural responses that are not exclusively associated with pain (as in Sneddon *et al.*, 2014), and are incompatible with the widely accepted definition of pain (Box 1), means that it will be increasingly difficult to levy any scientific argument against extending the regulations to all aquatic animals. There are also calls to abandon the distinction between animals that are "in our care" vs. wild animals, vertebrate, and invertebrate alike (Knutsson, 2016; Brennan, 2017; Knutsson and Munthe, 2017). Arguments put forward that would achieve the same end are, for example, that the moment a fish strikes a hook or lure it is "in our care", or the moment an aquatic animal enters a trawl, seine or gill-net, it is "in our care". From that moment, it would be covered by the regulations and we would have to treat it accordingly. In applications such as commercial capture fishing using trawls, seines, or gill nets, that is currently impossible. Thus, following the precautionary principle, to avoid the possibility of inflicting pain and suffering on fish, crabs, squids, octopods, krill, shrimp, etc., the only solution would be to shut down these activities, which would have sweeping social, economic, and food security implications. As Adamo (2018) states, "Given the present uncertainty regarding sentience in fish, caution should be applied regarding the precautionary principle. Adopting this principle may cause distress to humans, who are certainly sentient, as they strive to protect animals that may not be."

Decapods and honeybees are already regulated in some countries (Table 1). If the argument to include decapods under the regulations was successful, despite the uncertainties reviewed by Diggles (2019), it is likely that analogous arguments will be made to include all aquatic invertebrates. Diggles (2019) also points out that the evidentiary standard being applied to conclude that pain and suffering is possible cannot exclude insects or robots (also see Adamo, 2016a,b; Tomasik, 2017). Indeed, there are already discussions of sentience in plants (Pelizzon and Gagliano, 2015; Calvo *et al.*, 2017; Gagliano, 2017).

Despite the uncertainty surrounding the existence of conscious feelings in any animal, there has been a notable increase in the use of terms associated with human psychological disorders (often semantically linked with suffering) in the literature about aquatic animals. Although these are now numerous (e.g. articles referring to fish with anxiety disorders, anorexia, depression, aggressive personalities, coping mechanisms, etc.), readers can get a sense of such studies from that by Vindas *et al.* (2016) in which the authors conclude that their observations of serotonergic activation, increased cortisol production and behavioural inhibition in growth-stunted farmed Atlantic salmon (*Salmo salar*) are ". . .reminiscent of a depressed state, similar to those described in mammals. . .". This led to news articles with headlines such as, "Your salmon is probably really, really depressed —and may be suicidal" (http://metro.co.uk/2016/05/25/your-salmon-is-probably-really-really-depressed-and-may-be-suicidal-5903714/). It is difficult to see a scientific basis for using terminology associated with human psychological disorders when interpreting studies on lower vertebrates or invertebrates, because one could easily use terms that do not invoke human mental disorders, as has been the standard for decades in the ethology literature. Readers might consider the possibility that the growing use of terms associated with human psychological disorders has something to do with the legal requirement that an animal group or species must be sentient and experience pain and suffering to be included in the regulations.

It is important to be aware of how new animal groups or species get added to those already covered by the regulations. Either nationally or internationally, the organization charged with such matters will be asked for a scientific opinion on the matter. These institutions will then conduct a literature review and possibly a meta-analysis, which is typically discussed by an internal panel, often supplemented by external experts. The process can take months to years and typically ends with a report (e.g. EFSA, 2005, 2009; Swiss Federal Ethics Committee on Non-Human Biotechnology, 2014; Le Neindre *et al.*, 2017). Those reports are then used as the basis for further discussions by the regulatory and legislative bodies (in which all stakeholders are involved), which may or may not decide to follow the recommendations. Scientists involved in this process must be disciplined, remaining impartial and offering only the best and most up-to-date scientific information. Approaches to accomplishing this, even when faced with very limited and uncertain science, have been developed (e.g. EFSA, 2014, 2018). They must scrupulously avoid conflating the science with ethics or philosophy. However, that is not always the reality of these processes, as there is a tendency for those with strong positions on either side of the debate to become involved. Often, it is simply the balance or imbalance of personalities who happen to be appointed to the committee that

determines the outcome—that is, the science does not play the deciding role, particularly when it is inconclusive. We are particularly concerned that the scientists with the most experience with/knowledge of the animals concerned often opt out of participating in such committees, or are unaware of their existence.

When the issue to be debated by the regulatory authorities and lawmakers is one such as animal welfare, it attracts those—on all sides—who are deeply invested in the outcome. As an example, the Center for Animal Law Studies, and Lewis and Clark Law School, recently launched the Aquatic Animal Law Initiative (AALI). The AALI ". . .works to protect and promote the interests of aquatic animals by: advocating on their behalf through the legal system; promoting their value to the public by providing education about their cognitive, emotional, and physiological capacities; and harmonizing human, animal, and environmental interests." Some of their priority areas are to work towards obtaining regulatory protection for fish within the United States Animal Welfare Act, to reduce the use of aquatic species in testing of chemicals and toxins, and to address the impacts of aquaculture on animals as well as on the natural and human environments. The AALI is linked—via common participants—to the Humane Society of the United States and to similar law school initiatives in Switzerland, the UK and Australia, as well as to the Oxford Centre for Animal Ethics. Another example is Sentience Politics, an organization associated with the Effective Altruism Foundation, that advocates ". . .for a society in which the interests of all sentient beings are considered, regardless of their species membership. . .". Sentience Politics organizes ". . .political initiatives, publish scientific policy papers, and host conferences to bring forward-thinking minds together to address the major sources of suffering in the world." The Effective Altruism Foundation is also associated with Wild-Animal Suffering Research, an organization that conducts research on wild animal suffering, vertebrate and invertebrate. They state that, "suffering in nature is suffering we should prevent."

The implications of this are clear: whether supported by sound and unequivocal science or not, we are moving toward a situation where human interactions with/use of all aquatic animals will be far more restrictive than it is today, at least in the world's most affluent countries. Importantly, we are not arguing that the treatment of aquatic animals by humans should be unregulated. Rather, we are drawing attention to the weaknesses——at this time—of the scientific basis for regulating all aquatic animals on the presumption that they might be sentient and allegedly experience pain and suffering, and the consequences of accepting that position.

What does it/will it mean?

We will now explore some of the consequences of the current situation, and extend it to the future scenario in which some countries have adopted the most stringent welfare regulations and include all vertebrates and invertebrates. This exercise is relevant and needed in the context of weighing the perceived risk of inflicting pain and suffering on aquatic animals (if, in fact, they can experience pain and suffering) against the effect on society of implementing regulations that cover all aquatic animals, in all of the myriad forms of human interactions with them. Such a balanced risk assessment—that includes all stakeholders—should always be undertaken, and particularly if the precautionary principle/benefit of the doubt approach is being applied (in the absence of clear scientific support) as the basis for the regulations.

Aquatic animals in research

The opinion that fish, and some invertebrates such as decapods and cephalopods, can experience pain and suffering was adopted by the European Food Safety Authority in 2009 (EFSA, 2009). This led to the inclusion of fish and cephalopods in Directive 2010/63/EU on the Protection of Animals used for Scientific Purposes in the European Union (notably, not decapods, despite the recommendation in the EFSA opinion). As noted above, some other countries also regulate decapods (Table 1). The Directive stipulates, among other things, that approval by national animal welfare committees is required for research involving these aquatic animal groups. Some national animal welfare committees have a legal requirement to involve stakeholders other than scientists in the evaluation of proposals, sometimes including delegates from animal rights groups, theologians, and philosophers. In principle, the latter are present to opine on whether the benefits of the research to society outweigh the potential pain and suffering that would putatively be inflicted on the experimental animals (i.e. an ethical assessment that goes far beyond the science itself). To be prudent, one must now start the application process 8–12 months in advance of the work. Even then, the application might be denied, or modifications required, further delaying the work, or terminating it. To be clear, we are not arguing against the need for welfare protocols or for a cost-benefit analysis grounded in ethics. We are only identifying the growing constraints on researchers. Over time, unless the approvals process is streamlined, this scenario will reduce the number of researchers in these areas, since it would be an unacceptable risk to engage a graduate student in a project that might not be approved, or only be approved half-way through the student's studies. Another disconcerting and ironic result of this process is that research that contributes to a better understanding of aquatic animal sentience, pain, and suffering—that might lead to improving their welfare—is less-and-less likely to be approved (Allen, 2012; Rose *et al.*, 2014).

The three Rs principle is now widely applied by animal welfare committees, which requires that the minimal possible number of animals be used. This is not always practical, and risks decreasing the sample size and replication to levels that might compromise the strength of the inferences that can be drawn from the experiment and, thereby, its relevance to policy-makers, resource managers, or fishers. Applying the three Rs principle to experiments with the early life stages of some aquatic animals is particularly problematic because, even under the best conditions, they often have high natural mortality and, therefore, if your initial numbers are small, you will quickly have no animals to sample or observe. This is particularly troublesome in research on new species being developed for aquaculture, in which the fecundity of a single female can be in the thousands to hundreds of thousands and larval mortality in the early stages of research to develop appropriate husbandry techniques can be >90%.

Relatively small-scale field surveys that involve direct physical interaction with fish (tagging, measuring, stripping eggs or milt. . .), cephalopods and, in some countries, decapods, also require approval. If the approach above is applied to scientific population census surveys of fish in the wild (e.g. with gill-nets, fyke nets, trawls, seines), dramatic changes in current practice will be required as each fish will have to be rendered unconscious and insensible before it is euthanized. That will, at the very least, greatly reduce the sample sizes in such surveys. If planktonic

invertebrates are eventually covered, the individual animals contained in a plankton tow would have to be rendered unconscious and insensible before they are killed—that is, direct immersion in formaldehyde or alcohol will not be accepted. Technically, even today, a plankton sample that contains a larval fish that is at the exogenous feeding stage, cephalopod or (in some countries) decapod larva, should not be preserved without removing those animals and euthanizing them using an endpoint method that is accepted for those animals, although no one currently knows what that would be.

The trend in scientific publishing is for journals to apply the most stringent guidelines currently adopted anywhere in the world when it comes to the use of aquatic animals in research. In practice, this means that, even if you obtained approval for your experiment in your own country, or the aquatic animal group that you worked on is not covered by the regulations in your own country, the journal may still refuse to consider the work for publication. Some journals now ask reviewers to provide feedback on the ethical appropriateness of a study, shifting the focus away from peer review of scientific content and opening the door to rejecting a piece of work on the basis of a subjective ethical judgement.

Any senior researcher who has been conducting research on aquatic animals for several decades would agree that some of their body of research would probably not be approved in today's regulatory environment, or at least be greatly constrained. If this trend continues, it could become very difficult to conduct research that would inform risk assessments of, for example, the impacts of anthropogenic activity—pollution, commercial fishing, CO_2, climate change, etc. — on aquatic animals and ecosystems.

Aquatic animals in aquaculture

The possibility that fish are sentient and allegedly experience pain and suffering when held in captivity has also become a prominent topic in aquaculture in the context of providing appropriate husbandry conditions and endpoints on slaughter (unconscious and insensible when killed). In response, policies designed to harmonize regulations surrounding fish welfare in aquaculture across Europe have been developed (e.g. Council of Europe, 2006; European Commission, 2017). In 2006, the Standing Committee of the European Convention for the Protection of Animals Kept for Farming Purposes released generic welfare recommendations for the protection of farmed fish (Council of Europe, 2006). The document promised to provide species-specific appendices outlining the holding conditions required to meet welfare standards. However, these were never released because members of the Council of Europe failed to reach the required unanimity, most likely owing to the general absence of research on the welfare of most cultured species (particularly invertebrates), making it difficult to develop so-called animal-based measures of welfare for farmed aquatic animals that are analogous to those applied to farmed terrestrial animals (EFSA, 2012). Nevertheless, policymakers and veterinarians in charge of controlling national welfare standards require farmers to produce simplified welfare checklists that are used to judge whether the husbandry conditions being provided are appropriate (Anonymous, 2013). While it is usually reasonably straight forward to measure the pathogen-based (e.g. virus, bacterial, or parasite load) or survival/growth-based welfare status of individuals, animal-based measures of the behaviour of farmed aquatic animals is much trickier in terms of establishing clear links to welfare state. The focus on individual behaviour as indicative of animal welfare is also a driver for the kind of research alluded to above on the so-called psychoses and coping mechanisms of farmed aquatic animals.

Aquaculture has rapidly become one of the most important sources of protein for human consumption, and is more efficient than the production of protein from farmed terrestrial animals (FAO, 2016a,b; Froehlich *et al.*, 2018). The impact of increasing welfare-related constraints on aquaculture (even when not supported by scientific evidence) is difficult to predict, even in terms of the desired effect of improving the welfare of the farmed animal. This, combined with the greater difficulty to impossibility of conducting research on these animals (as above), will leave society less able to produce high-quality protein to feed a still-growing global population.

Commercial capture fishing

There are growing calls for the development of animal-based measures of the welfare state of aquatic animals, and for the adoption of endpoints (unconscious and insensible at the time of slaughter) in commercial capture fishing (Metcalfe, 2009; Sandøe *et al.*, 2009). As stated above, the argument is that the moment the animal enters the capture gear it is "in our care" and subject to regulation. It is also important to note that the regulations associated with the care, welfare, and euthanasia of laboratory or farm animals focuses on individuals. It remains unclear how or if this can be practiced on commercial capture fishing or scientific surveys during which tons of fish, crustaceans, and plankton are collected under circumstances where it would be impossible to apply an individual-based approach to either assessing their welfare state or euthanizing them (Diggles *et al.*, 2011; Veldhuizen *et al.*, 2018).

Like aquaculture, capture fishing is a major source of high-quality protein for human consumption, and is also more efficient than the production of protein from farmed terrestrial animals (Hilborn and Tellier, 2012; FAO, 2016a,b; Poore and Nemecek, 2018). The impact of increasing welfare-related constraints on capture fishing (even when not supported by scientific evidence) could quickly lead to outright banning of gear such as gill-nets, and impose severe limitations on large-scale fishing using trawls and seines. This, combined with the greater difficulty to impossibility of conducting research that would be the basis for technological improvement, will leave society less able to produce high-quality protein, which would impose huge environmental and economic constraints and, more importantly, lead to food and nutritional insecurity, especially in poorer societies.

Recreational fishing

Accepting the premise that fish are sentient and experience pain and suffering has had a pervasive impact on recreational fishing, particularly in Germany and Switzerland (Arlinghaus *et al.*, 2009, 2012). In Germany, risk assessments weighing the presumed suffering of fish against the benefits to anglers, and to local economies and fish conservation from angling, has led to severe constraints or bans on competitive fishing, put-and-take fishing, and the use of live baitfish and keep nets. One of the key ongoing debates involves the voluntary catch-and-release of legal-sized fish. In contrast to the mandatory release of sizes or species protected for purposes of conservation, where the presumed

suffering associated with catch-and-release is considered ethically acceptable, the release of legal-sized fish is prohibited in some Federal states (Arlinghaus *et al.*, 2009, 2012). This is because catch-and-release fishing is deemed to cause unnecessary suffering to fish and the non-consumptive benefits to anglers are considered of insufficient weight in the risk assessment calculation (as opposed to the importance of fish conservation, which outweighs the risk of suffering). Thus, under such regulations, the only legally accepted reason for recreational fishing is to harvest and consume the catch, which leads to a far greater number of fish deaths caused by mandatory catch-and-kill policies. It can be argued that life is the major component of fitness/well-being and, hence, that catch-and-release has a lower welfare impact than catch-and-kill (Bovenkerk and Braithwaite, 2016).

To protect sea bass (*Dicentrarchus labrax*) populations, the EU recently implemented a catch-and-release only fishing policy on the recreational fisheries. When this conservation measure was launched, fisheries agencies in two German states imposed a ban on recreational fishing for sea bass (Arlinghaus, 2018). The reasoning behind the ban was that recreational fishing is only tolerated if the fish caught are consumed. Because that cannot be assured in the current recreational fishery, fishing for sea bass was banned overnight. This case is instructive because the intent of the EU policy was to conserve sea bass while maintaining the recreational fisheries. Rather, it opened the door to a complete ban on fishing, stemming directly from the precautionary principle/benefit of the doubt argument.

The narrowing of opportunities for people to engage in fishing undermines an important source of concern for aquatic animal welfare and fish conservation (Bate, 2001; Schwab, 2003; Rose 2007). In contrast, positive messages to consider fish welfare in recreational fisheries can quite easily win the support of anglers, benefitting the fish, angler, and fishery (Cooke and Sneddon, 2007, Arlinghaus *et al.*, 2007b, 2009; FAO, 2012).

Ornamental fish keeping

Ornamental fish keeping in ponds and aquaria has been a popular pastime for centuries. Millions of fish are kept under conditions that are difficult/impossible to assess or monitor, let alone regulate. Many hobby fish keepers will also regularly carry out their own breeding and crossing experiments. In contrast to the situation in research, such experiments are done without any form of external control or approval. This is an example of the inconsistency in regulatory standards in current aquatic animal welfare policies in Europe: they apply to researchers, aquaculturists and, in some countries, to recreational anglers, but not to ornamental fish keepers, aquaria and zoos. One reason for this is the impracticality of it. This too may soon change, with calls for reconsidering the practice of feeding animals in zoos and aquaria live invertebrates (Keller, 2017), or ending the practice of keeping animals in captivity (e.g. Born Free Foundation).

Losing ornamental fish keepers would undermine a large support base for the welfare of aquatic animals and their conservation (Cracknell *et al.*, 2018), and risk millions of jobs worldwide, particularly in developing countries (Costa Leal *et al.*, 2016).

Moving forward

What if fish and/or aquatic invertebrates are not able to experience pain or suffering? Would the issue of their welfare cease to exist? It would not, because one could address fish welfare using indicators other than those based upon a pain-centred perspective (Arlinghaus *et al.*, 2009; Diggles *et al.*, 2011; Diggles, 2016a). To move forward and design strategies for avoiding the surprisingly counter-productive and sometimes inconsistent outcomes that a pain-centred policy has to offer for the welfare of aquatic animals, two directions are worth contemplating.

First, a sober look at the welfare of aquatic animals would exclusively focus on objectively measurable welfare indicators such as behaviour, physiology, growth, fecundity, health, and stress (Arlinghaus *et al.*, 2009). Obviously more species-specific research would be needed before these indicators could be put into practice (EFSA, 2012). Unfortunately, owing to the current precautionary principle/benefit of the doubt approach toward largely accepting, *de facto*, that fish and other aquatic animals are sentient and experience pain and suffering, it is increasingly difficult to conduct this research.

Second, more emphasis could be placed on the win-win reality that everyone benefits from keeping aquatic animals in a high state of welfare during capture, holding, husbandry, and through slaughter (e.g. Diggles, 2016b). Indeed, it is in the interest of the researcher, aquaculturist, and ornamental fish keeper that fish held in captivity live well, and in the interest of the commercial fisher that fish captured in a trawl maintain high flesh quality and, thereby, receive a high market price. There is also a growing insistence among consumers that the animals that they are eating were well treated. Similarly, it is in the interest of recreational anglers to ensure that released fish survive unharmed and reproduce. Self-interest, assisted by recommendations based on scientifically established welfare indicators that are not based on alleged pain, would be an effective way to minimize or even avoid many of the situations mentioned above. It would also provide a positive and constructive message that, we argue, is more likely to gain the support of stakeholders (e.g. Arlinghaus *et al.*, 2009).

There are surely some lively debates and tough choices ahead. We hope that this essay will serve to help those involved to identify sound science and the key questions on which more research is needed (or those that science cannot resolve), as well as highlighting the need to stringently separate the scientific evidence from the ethical debate. In the end, extending legal protection to aquatic animals is a societal choice, but that choice should not be ascribed to strong support from a body of research that does not yet exist, and may never exist, and the consequences of making that decision must be carefully weighed.

Disclaimer: The opinions and positions taken in this article are those of the authors and do not necessarily reflect those of their employers, ICES or OUP.

Declarations of interest

H.I.B. works for the Institute of Marine Research, Norway, a government research institute charged with generating science and providing advice in support of the sustainable use of marine resources. He conducts research on aquatic animals. None of the directed funding he has received to date has been related to fish sentience-pain-suffering. He is Editor-in-Chief of this Journal, which is owned by the International Council for the Exploration of the Sea (ICES), a global intergovernmental organization that develops science and advice to support the sustainable use of the oceans. He declares no conflicts of interest.

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