Can photonics technologies contribute to sustainable harvesting of marine life

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Abstract. Humanity is depending on sustainable management of our common natural resources. Nature has got some premises that can not be violated without consequences. The oceans resources and ecosystems are heading for collapse if measures are not taken to change the course. New approaches based on science and gained knowledge about well working principles and innovative methods employed by marine predators can serve as inspiration to disrupt and rethink the way we perform harvest of marine resources. Humpback whales create bubble nets and make ‘walls of sound’ as a hunting strategy. Snapping shrimps use their claws to generate bubbles that cavitate to stun their prey. Inspired by nature, can we copy and apply principles from such performance in a future harvest methodology? And can photonics technologies play a role in this?

1. Context and background

From ancient times, fishing has been a vital source of food for humanity and a provider of employment and economic benefits to those engaged in this activity. Today, harvesting of fish has grown into a major industry with global value chains. The most recent version of The Food and Agriculture Organization’s (FAO) ‘World review of fisheries and aquaculture’ (FAO, 2018) states that the global marine capture was 79.3 million tonnes in 2016, and estimates that 40.3 million people were working in this sector same year.

For millennia there have been no significant developments in the performance of fisheries. But this has changed. Especially in recent decades the world’s fishing fleets have been subject to modernization and innovation, enabling them to be highly efficient in harvesting the oceans resources. These developments have resulted in making the marine life totally accessible as remote locations and deep waters are no longer obstacles in the vessels search for fish. The world’s super trawlers now have the capacity to harvest quantities of fish that were unthinkable in the past.

However, there is a dark side to the industry. Although the marine resources are renewable and therefore in theory limitless, the increased fishing activity around the globe has caused collapse of commercial stocks not just once, but several times, over the last forty years. The collapse of the cod fishery off Newfoundland, and the 1992 decision by Canada to impose an indefinite moratorium on the Grand Banks, is a dramatic example of the consequences of overfishing. Another example is the collapse of the North Sea mackerel in the 1970s. And last, within a few years of the introduction of seine fishing in the 1960s, the stocks of the North Sea herring collapsed. In the latter example the stocks seem to recover.
Discard of unwanted catch due to not market optimal sizes or quality, by-catch of mammals or endangered species, bottom habitat damage and lost or abandoned gears and nets which continues to fish ("ghost fishing"), can be listed additionally as related challenges and pose huge threats to the marine ecosystem and aquatic life. Several of these challenges are linked to the fishing practices and current methods in use.

According to the FAO report mentioned above, in the marine fisheries 33.1 percent of stocks were classified as overfished in 2015. This urgent need for change is commonly agreed amongst most of the world’s nations and is prioritised and explicitly expressed as a target in the United Nations Sustainable Development Goals (SDGs) 14: to “Conserve and sustainably use the oceans, seas and marine resources.” Fishing practices and methods are further outlined in 14.4: “By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics”.

In the ocean, innovative and advanced hunting methods are employed when aquatic predators target their prey. Can the principles of such performance be copied and applied to a man made catching methodology? The objective of this paper is to challenge and disrupt the way we think about how industrial fisheries are and can be conducted. The overall goal is to contribute to development of sustainable fishing practices.

2. Catch quality and animal welfare implications of current industrial harvesting methods
The most common current methods of catching fish can be grouped as follows: trawling; purse seining; gillnetting; longlining; trolling; pole-and-line fishing; harpooning; jigging lines; angling.

Other current methods have several implications. Catch practice is directly connected to the potential of value creation as the methods in use is one of the key factors affecting the quality of the catch. Internal and external injuries are typical and inevitable consequential damages from catching operations and handling. Even when gentle methods are applied where the intention is to deliver the catch alive, there is great mortality. The deterioration in catch quality which occurs in this first link of the seafood value chain is critical and cannot be retrospectively rectified. The unrealised economic potential this entails is a loss that affects both the value chain and society as a whole.

Another issue is related to animal welfare. Awareness to fish welfare has gradually increased in recent decades, in policy, research and society in general. During catching operations fish are pursued to exhaustion, crushed under the weight of other fish in trawl nets, raised from deep water resulting in decompression injuries such as burst swim bladders. They are snared in gill nets, confined in constricting seine nets, spiked with gaffes as they are brought onboard, caught on hooks, and left often for hours or days. Does this treatment have any impact on animal welfare and quality of the product?

There are, however, still many gaps in our knowledge of the welfare of fish, and scientists are still in debate as to whether fish can feel pain, however, there is increasing scientific evidence to suggest that this is indeed the case. That fish are able to feel pain has been confirmed by the EFSA (European Food Safety Authority) and OIE (World Organization of Animal Health) (EFSA, 2009a; OIE, 2017). In 2017 EFSA argued that fish should be treated in the same manner as mammals and birds when it comes to consciousness and welfare. Under EU law fish welfare is covered by Article 13 of the Lisbon Treaty. It states: “In formulating and implementing the Union’s agriculture, fisheries, transport, internal market, research and technological development and space policies, the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals, while respecting the legislative or administrative provisions and customs of the Member States relating in particular to religious rites, cultural traditions and regional heritage.”

These provisions clearly apply to the welfare of both farmed and wild caught fishes. Targeting fish welfare issues in the industrial fisheries implies that the industry’s capture practice must be radically changed.
3. Ultimate goal: touch-free harvesting and catch handling of wild living fish
As illustrated above animal welfare, catch quality and the subsequent potential for value creation are closely connected to each other. In a quality perspective the ultimate goal is to bring the fish on board alive, unaffected and undamaged from the catching process, and keep them alive until deliberate slaughter.

To achieve such standards for the future will require the development of concepts and solutions for touch-free harvesting and catch handling of fish. This will only be possible if fish behaviour can be manipulated during catching operations. To achieve such a goal will require methods which enable fish to be herded and directed into a catching device equipped with containers suitable for live storage of fish. In addition, if such a device like this is further equipped with technology for catch identification then it will be possible to implement mechanisms for selection of specifically targeted catch individuals, enabling subsequent routing of individually selected fish into containers or release of undesirable catch. In today’s industrial fisheries, selective mechanisms and equipment are far from being efficient.

Can fish behaviour be manipulated by man? Or more precisely; can fish senses and their natural instincts be utilised in order to impact its performance? This approach implies finding a way to communicate with these aquatic animals.

The communication skills of any creature depend on what external stimulus they can perceive. This paper presents findings from marine science, with emphasis on hearing and sensory systems of fish. In addition, it presents examples how sea predators take advantage of and interact with such systems of targeted prey in their choice of hunting strategies.

4. Sensory systems and survival skills of fish:
Aquatic animals have a range of senses and like humans, fish have all five; sight, smell, taste, hearing and feeling.

All zoological life on planet earth use their sense systems to gather information on their surroundings. These systems are capabilities crucial for survival and reproduction. How creatures respond and act is based on what they do observe, hear, smell or feel. The choice of actions are closely connected to their instincts they possess. Instinct is the ability of an animal to perform a particular behaviour in response to a given stimulus immediately upon first exposure to the experience.

In addition to the sense systems and inherent specie specific instincts, all living creatures have some ability to learn. Learning is a change in behaviour which occurs as a result of experience. Animals may learn behaviours in a variety of ways.

This paper is especially concerned with the ability of marine creatures to learn through habituation. In this type of learning, animals decrease the frequency of a behaviour in response to a repeated and increased exposure to a stimulus. This occurs when the behaviour does not result in some type of benefit or reward. It is an adaptive strategy because responding to a stimulus when there is no benefit or reward is a waste of energy.

5. Photonics technologies interacting with the visual system of aquatic animals

5.1. Laser application in prawn fisheries Iceland
In Iceland a startup company, Optitog https://www.optitog.com/, has developed a system which applies laser technologies in their catching process. The invention has the objective to replace conventional trawl with a new type of fishing gear that herds fish by using a virtual trawl-shaped net. The net is formed by projecting directed light through sea water, without touching the sea floor, leaving the benthic habitat undisturbed. The intention is also to reduce by-catch, leave escaped fish unharmed and dramatically reduce oil consumption. So far the technology has been applied to harvesting of wild prawns. The invention is based on taking advantage of the visual system of aquatic animals, the lasers emit light, making an illusion of a barrier, and thereby attempting to modify the behaviour of the prey in a desired manner.
5.2. Use of artificial light in the fisheries
Applying laser technologies in the harvest of marine life is a modern twist of an ancient and well proven technique. The use of artificial light as a stimulus to attract and accumulate fish prior to harvest has had a long history, dating back thousands of years.[1]

The responses of fish to light and how their visual system works, has been the subject of marine research for decades. Findings, relevant to this paper, show that the colour (or wavelength) produced by an artificial light source can strongly influence behavioural responses in marine organisms.[2] There is also evidence showing that each species has an optimal wavelength to which they respond and illumination level where they show a tendency to congregate.[3]

5.3. Can use of lasers have a herding effect on fish?
Experiments have been conducted to examine the herding effect of a moving laser screen, He-Ne laser light, at different fish numbers (10, 20 and 30 fish) and different species (Japanese dace Tribolodon hakonensis, carp Cyprinus carpio and rainbow trout Oncorhynchus mykiss). They discovered that “laser temporally dispersed fish school, and then fish again swam in school avoiding the laser. Thereby laser can drive fish into an area of tank. Fish are, however, considered to learn to escape through laser screen, since herding effects decreased, following repeated exposure to the stimuli of laser screen. Laser could herd fish more effectively in the dark than in the light at the indoor tank experiment. The larger fish number of Japanese dace was, the sooner laser screen could herd. Moreover, the herding effect was different among species. It is therefore resulted that the herding effect depends on several factors e.g. fish school behaviour and swimming performance.”[4]

From this research and much supporting evidence from similar work clearly establish the herding effects which can be induced through the use of lasers and that it doesn’t have a lasting or stable effect. The question remains as to whether a more stable herding or schooling effect could be achieved through additional stimuli interacting with for instance the hearing systems with acoustics.

6. Innovative and advanced catching methods employed by marine predators which take advantage of the auditory systems of target prey

6.1. Basic insight: How does fish detect acoustic signals?
The majority of fish species are known to detect sounds from below 50 Hz up to 500 or even 1,500 Hz. A smaller number of species can detect sounds to over 3,000 Hz, while a very few can detect sounds to well over 100 kHz.[5]

6.1.1. Fish have evolved two sensory systems to detect acoustic signals: the ear and the lateral line.
Fish do not need an outer or middle ear, since the role of these structures in terrestrial vertebrates is to funnel sound to the ear and overcome impedance difference between air and the fluids of the inner ear. Since fish live in water, there is no impedance difference to overcome. Fish do have an inner ear which is similar in structure and function to the inner ear of terrestrial vertebrates. The most important similarity between the ears of all vertebrates is that sound is converted from mechanical to electrical signals by the sensory hair cells that are common in all vertebrates.

6.1.2. Swim bladder plays a role. In fish with a swim bladder, the acoustic sound pressure can indirectly stimulate the fish’s inner ear via the bladder. For the stimulation to be efficient, the swim bladder either must be close to or have a specific connection to the inner ear. In one form, a gas bubble makes the mechanical coupling; in another the inner ear is directly connected to it by a set of small bones called the Weberian ossicles. Since the air in the swim bladder is of a very different density to that of the rest of the fish, in the presence of sound the air starts to vibrate. In these cases the fish are sensitive to both particle motion and pressure modes of sound, leading to enhanced pressure detection a broadened frequency response range.[6]
6.1.3. Fish listen with their body. The lateral line consists of a series of receptors along the body of the fish enabling detection of hydrodynamic signals (water motion) relative to the fish. It is involved with schooling behaviour, where fish swim in a cohesive formation with many other fish, and for detection of near-by moving objects, such as food.[6]

6.1.4. Data about hearing systems and behaviour responses for different fish species are available. Such data provides information about the range of frequencies that fish can detect and the lowest sound level they are able to detect at a particular frequency. This level is often called the “threshold”. Sounds that are above threshold are detectable by fish. Hearing thresholds have been determined for perhaps 100 species.[7] The data and scientific information about the hearing sensory systems to the most commercial species are reachable knowledge.

6.2. Whales create bubble nets and sound walls when hunting
Scientific research over the last fifteen years has produced a growing body of evidence that humpback whales do apply acoustic effects when creating bubble nets to trap herring in a quiet and bubble-free water zone in the centre of the bubble net.[8]

It has been known for decades that, to trap prey, humpback whales sometimes employ ‘bubble nets’ in the form of hollow cylinders. The cylinder wall contains a dense population of bubbles, but the interior is comparatively bubble-free. A group of whales may cooperate, diving and then rising in a helix, releasing bubbles to form nets of 3 to 30 meters diameter. The prey congregates in the bubble-free centre and are then consumed by the whales, which rise from below. When the whales form such nets, they emit very loud ‘trumpeting feeding calls’, the available recordings containing energy up to at least 4 kHz.

The scientists also made findings how the bubble nets are linked to use of sound. It’s been established that the void fraction of the profile would cause the wall of the cylinder to act as a waveguide, creating a ‘wall of sound’ with a relatively quiet interior at the centre of the cylinder. It was hypothesised that any prey which attempted to leave the trap would enter a region where the sound is subjectively loud, be startled, and in response school (the bubble net turning the ‘schooling survival response into an anti-survival response). Furthermore, they found that the trumpeting calls encountered in the ‘wall of sound’ are appropriate for exciting swim bladder resonances in the prey. Either or both effects are believed to cause the prey to remain within the bubble net, and so trap the ready for consumption.

6.3. Snapping shrimps create bubbles which cavitate and generate sounds to stun its prey, deter predators, and communicate with others
Snapping shrimps are crustaceans that are found in tropical and temperate seas. These shrimps, usually a muddy green colour and grow to about 5 cm (2 inches) long. Their most noticeable physical feature is a claw which can grow to be half the size of it’s entire body length. It is this claw which gives snapping shrimp it’s most remarkable attribute. A snapping shrimp will quickly close its claw to produce a loud ‘snap’ and generate a percussion wave as a way to stun its prey, deter predators, and communicate with others. For at least one species of snapping shrimp, the actual sound is generated by the formation and subsequent popping of a bubble, and not by the physical contact of the claw striking together. The bubble appears when the shrimp closes the two parts of the enlarged claw at lightening speed, causing the water to cavitate. Scientists have also found that light is produced when the bubble pops due to the high temperatures and pressure inside the bubble.[9]

6.4. Hypothesis: hearing systems and instincts of marine animals can be utilized in a future harvest methodology
The illustrations above clearly demonstrate that predators through emitting specific sound can induce startling and schooling responses in prey. The research is inconclusive on the extent to which the
induced behaviour is the result of a combination of sound and visual effects or just one working stimulus, but use of sound is the denominator in these illustrative examples.

The findings indicate that the responses of prey are related to instincts, but perhaps more interestingly, the responses seem to be stable, and the schooling or herding effects do not decrease with exposure. Based on this it can be hypothesised that use of sound is the success factor in the hunting and catching methods in use by such predators.

7. Relevant photonics technologies holding potential for marine applications

Inspired by nature, technologies that have the capabilities to emit both light and sound or vibrations which can impact the sensory systems and natural instincts of fish, are of great interest when sketching new concepts of marine catch methodology.

A patent that may hold relevance is US7260023B2T, assigned to US Secretary of Navy in 2006. The invention consists of a technology which uses flashes of laser light to remotely generate underwater acoustics.[10] Sciencedaily [11] is describing the invention in few words:

“Efficient conversion of light into sound can be achieved by concentrating the light sufficiently to ionize a small amount of water, which then absorbs laser energy and superheats. The result is a small explosion of steam, which can generate a 220 decibel pulse of sound. Optical properties of water can be manipulated with very intense laser light to act like a focusing lens, allowing nonlinear self-focusing (NSF) to take place. (…….) In addition, the slightly different colours of the laser, which travel at different speeds in water due to group velocity dispersion (GVD), can be arranged so that the pulse also compresses in time as it travels through water, further concentrating the light. By using a combination of GVD and NSF, controlled underwater compression of optical pulses can be attained (…….) Also, commercially available, high-repetition-rate pulsed lasers, steered by a rapidly movable mirror, can generate arbitrary arrays of phased acoustic sources. On a compact underwater platform with an acoustic receiver, such a setup can rapidly generate oblique-angle acoustic scattering data, for imaging and identifying underwater objects. This would be a significant addition to traditional direct backscattering acoustic data”.

This was an invention back in 2006, there are reasons to believe that there have been extensive developments and advancements within this field since then. Technologies within this field should be mapped and further explored for possible marine applications.

8. Call for collaboration TIMOC project- field experiment

TIMOC (Transparency In the Moment Of Catch) Initiative is a project aiming to contribute to sustainable harvesting of marine life by mapping technologies that might hold potential for application in a new approach to and catching methodology enabling future harvest and catch handling of marine life to be touch-less on the premises of nature.

Photonics technologies are of great interest and the project is therefore reaching out to these environments holding such expertise with the aim to get answers to the questions that are on the table. If the mapping phase succeeds in finding applicable technologies then the project intends to call for partners within this field in order to pioneer and test a pilot project.

8.1. Description of the experiment

TIMOC Initiative is hoping to be able to conduct a field experiment where technological equipment like lasers and the necessary attributes will be deployed in seawater at test locations. The goal is to investigate whether lasers emitting light in combination with acoustic signals can be used to herd and direct fish and other aquatic animals into enclosure.

Additionally we want to investigate the flexibility of the equipment, whether the lasers and acoustic beams can be remotely controlled based on the movements or the location of the animal. The objective is to examine whether the targeted fish react to the acoustic frequencies as a physical barrier or and can be directed or lured into an enclosure. The frequencies will be selected based on the knowledge available about which frequencies the species respond to.
In a first aspect of an experiment a device has to be applied, adjusted or engineered suitable for guiding or herding aquatic animals. The device has to comprise laser emitting acoustic signals, where the sound emitted hypothetically has a schooling or repellent effect to the fish, and where the aim of these signals is to guide the fish by restricting its movement in at least one direction. The device should comprise at least one constrainer portion operational with the sound source, where the sound source or sound sources form a beam, wall, pattern or feature in a water column and or at the bottom of the water/ocean.

In a second aspect of the experiment a method will be tested for guiding aquatic animals using at least one sound source, wherein the sound emitted by the lasers is repellent to the animal and where the sound is directed to guide the animal by restricting its movement in at least one direction. Sound beams or walls will be tested if suitable for guiding aquatic animals in a body of sea to a collecting unit for retaining the catch.

In the present context the term ‘sound’ refers to acoustic signals that are within the range of the aquatic animals hearing capabilities including their capabilities to sense frequencies and subsequently have an impact on their behaviour.

In the present context the term ‘guiding’ refers to directing the movement or migration of marine species or herding the marine species in a specific direction or towards a predetermined location.

In the present context the terms ‘enclosure’ or ‘constrainer portion’ refers to any construction, device or gear to enclose, hold or remove aquatic animals from the water, such as, but not limited to a unit that fish can be collected into; a trap, a cage, submersible cage, a ship or a suitable landscape.

8.2. Field experiment at Butrint lagoon, Albania

In September 2019 the project was exploring possible test locations suitable for conducting a field experiment. In Albania we found Butrint lagoon and got in touch with Mr. Doni Qurku, who holds a license to fish and cultivate fish at this lagoon. This license holder found this project very interesting and offered his help and cooperation if the project can take place. Mr. Qurku offers to provide and facilitate access to both wild living fish (Seabass) and caged fish (Seabass cultivation), under his license.

8.2.1. Butrint lagoon. Butrint lagoon is a salt lagoon south of Saranda, Albania, located in the direct proximity of the Ionian Sea. It is surrounded by dense forested hills, rocky coast and complemented by saltwater and freshwater marshlands. The lake has a length of 7.1 km (4.4 mi) and a width of 3.3 km (2.1 mi), with a surface area of 16 km² (6.18 sq mi). The maximum depth of the lake is 24.4 m (80 ft). At the south, the Vivari Channel connects the lagoon to the sea. (Wikipedia, YouTube link)

8.2.2. Targeted fish species. Main fish species of commercial interest and thus targeted as experiment objects are European Seabass (Dicentrarchus labrax) and Seabream (Sparus aurata), both are present in this lagoon. The European seabass has increasingly been used in the study of anthropogenic noise effects on fish. Information and data about the hearing system and response to noise and their collective behaviour, have been collected during these studies and are available. This proposed pilot at the lagoon can therefore benefit from this knowledge. A summary and some details about the hearing system of Seabass can serve as an example of available data.

8.2.3. Seabass hearing system, example. The hearing sensitivity of Seabass is most acute at low frequencies (100-1000 Hz; ref Lovell, 2003). The scale of the behavioural responses depends on the nature of the noise (ref Neo et al., 2014). Further, startle responses are known to occur after exposure to low frequency sounds (ref Kastelein et al., 2008). Changes in physiological and biochemical parameters were also found in response to low frequency impulsive and continuous noise (ref Santulli et al., 1999; Buscaino et al., 2010; Bruinjes, 2013; Bruinjes et al., 2014; Debusschere et al., 2016). Like most fishes, hearing in D. labrax may be dominated by the particle motion element of sound (ref
Popper and Fay, 2011), but because they have a swim bladder they are also likely to be sensitive to changes in pressure (Wysicki et al., 2009).

8.2.4. Stakeholders Butrint lagoon. An experiment at the Butrint lagoon would require involvement and permission from the responsible bodies. The highest governmental body responsible for environmental issues of Albania is the Council of Ministers. The functional jurisdiction of Butrint lagoon is divided between different public administrative bodies such as the Ministry of Urban Development and Tourism; Ministry of Environment; and Ministry of Agriculture, Rural Development and Administration of Waters. A very important decision-making body joining representatives of the above ministries, international organisations and NGOs is the National Board of Butrint Park. (reference article Application of DPSIR framework to a Mediterranean Transitional Water Body: The Butrint Lagoon, Southwest Albania)

9. Closing comments
The project has encircled patents and solutions where lasers can be used to create underwater acoustics. As the project lacks the competence to judge whether the solutions hold potential for new applications like the one described in this paper, we reach out to the industry, trying to get in touch, in search for qualified answers to our questions.

Head of Project, Eva-Kristin Varheim, intends to attend the ICDT conference in Nanjing 26.-30. October 2020, hoping to connect with relevant players and expertise to discuss possibilities that laser technologies hold, and eventually find collaborators to a field experiment in Butrint lagoon, Albania.

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