Inexpensive Seawater Tester Probe for Scientific and Artisanal Fishing Purposes

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Summary

Efficient, inexpensive technologies to monitor physical and chemical parameters in seawater can have significant commercial and scientific benefits if properly used and managed in a spirit of partnership, cooperation, and understanding. More than ever before, our oceans need sustainable solutions.

Executive Summary

The Chilean region of Aysén has 19 fishing coves operated by artisanal fishermen who depend on fish –sea urchin in northern Aysén, southern hake and other species in central Aysén– for their livelihoods. The conservation status of these resources and the precarious existence led by the fishermen are a cause for concern.

The climate crisis has raised seawater temperatures, causing changes in marine wildlife. We do not know for certain how ocean resources are faring in the face of such abrupt shifts.

These circumstances call for new technologies enabling fishermen to actively monitor their fisheries management zones; for example, for seawater temperature, a factor that directly impacts fish behavior. This would improve fishing opportunities and sustainable resource management by artisanal fishermen. In addition, the region can make a valuable contribution to marine research. Because of its subantarctic influence, scientists regard Aysén as highly suitable for the study of biodiversity and climate change. What is the region's actual biological productivity? What effect is the climate crisis having on its structure?

Plenty of ocean research technology and equipment exists, but it tends to be costly and often unaffordable to local researchers and to the communities that depend on marine resources. What we propose is an inexpensive tester probe based on affordable, reusable, easily-configured Arduino boards and compatible sensors, focusing on physical and chemical seawater parameters of importance to commercial fishing and to several fields of study. Sensor, electronic and waterproofing systems have performed well in preliminary testing conducted in riverine and lacustrine settings.

These solutions could help improve living conditions in local communities reliant on sensitive marine resources being impacted by the climate crisis and extractive activities. They could also help understand how –or whether- ecosystems are adapting, in an unprecedented "citizen science" partnership between fishermen and academics.

Contents

Background and Introduction

The Intergovernmental Panel on Climate Change (IPCC) reports that the planet has been undergoing rapid climate change since the nineties (McCarthy et al. 2001). Warming by 1.4 to 5.8 ºC expected in 1990-2100 (IPCC 2006) could drastically alter all known patterns of life on Earth. Recent studies (Broennimann et al. 2006; Thuiller et al. 2006; Araújo et al. 2005a; Araújo et al. 2005b; Pearson & Dawson 2003; Bakkenes et al. 2002; Peterson et al. 2001) agree that global warming affects biodiversity in different scales and forms, including species range and composition, displacement in altitude and/or latitude of ecosystems and plant communities, and changes in the functioning of ecosystems.

Marine fish and invertebrates respond to ocean warming by changing their range (López, 1968; Lastra & Ciechomski, 1988), generally to higher latitudes and deeper waters. Fishing is impacted by this "tropicalization" of fish captures (Belkin, IM 2009). Ocean warming has impacted worldwide fishing through the past four decades, highlighting the pressing need to develop plans designed to minimize its effects on the economy and food security of coastal communities (Allison, EH et al. 2009).

South Pacific marine ecosystems have undergone significant change in recent decades (Edgar, 1997; Thresher et al, 2003). Changes in the range of marine populations can impact their availability for fishing. The spatial distribution of marine fish and invertebrates depends largely on the connection between physiological optimums and limits at different temperatures, oxygen levels, and other biotic and abiotic conditions (Sunday, J. M. 2011).

Biological diversity in oceans is affected by both environmental and anthropogenic phenomena, including natural resource (aquaculture, fishing, forestry) exploitation, urban and industrial growth, and contamination.

Key effects on fisheries include resource depletion on a worldwide scale (Schojet, 2002). As reported by UNEP (2011), fishing is proceeding at twice the ability of species to reproduce, sparking an increase in world reserves that are overfished (32% since 1992) and in full production (13% since 1992) and a decrease in under- and moderately fished reserves (49% since 1992). The Living Planet Report 2012 notes that marine ecosystem biodiversity has diminished by a dramatic 22% in 1970-2008.

Aysén has 19 fishing coves operated by artisanal fishermen who depend on fish for their livelihoods. The definition of artisanal includes fishing conducted by individuals personally, directly and consistently, as well as zone management by entities made up exclusively of registered fishermen. The definition also encompasses ocean-going boats under 18 m in length, divers, and seaweed and shore gatherers (www.sernapesca.cl). Regional artisanal fishermen catch southern hake, pink cusk-eel, yellownose skate, and sea urchin. Resource conservation is a matter of concern and fishermen often lead a precarious existence (Moreno et al. 2006). Moreover, this region of estuarine fjords and channels is being strongly impacted by the forestry, tourism and aquaculture industries. While this development remains incipient, it requires environmental baselines set under the current pristine conditions to enable quantification of future changes, and if at all possible, to anticipate change through modelling.

How marine resources are faring is not known for certain. Most research on seawater temperature, salinity, dissolved oxygen and nutrients in the vast ocean area between the Gulf of Corcovado and San Rafael Lagoon is largely based on the work of Brattström & Dahl (1951), Pickard (1971; 1973), Pickard & Stanton (1980), Vargas (1983), Sievers & Prado (1994), Silva et al. (1995; 1997; 1998) and Guzmán & Silva (2002), with recent studies by the Center for Patagonia Studies 2017 (CIEP).

Because of the impact of human activity and the climate crisis, obtaining marine environment data is crucial for planning future development in terms of food security and resource utilization by regional coastal communities, ecosystems conservation, and scientific knowledge of their functioning and adaptation to change. Yet, a better understanding of the ocean environment requires a well-planned effort, qualified people, and above all, equipment and instruments to measure the physical, chemical and biological factors involved.

Mainstream researchers buy or develop technologies and instruments at a high cost, since these are multi-parameter devices that must withstand extremely harsh conditions.

The industrial fishing sector understands well the advantages of leading-edge technology. The Chilean industrial fleet is equipped with echo sounders, satellite navigation, sonar, video cameras, radio and compass, providing the ability to monitor the seabed and banks of fish while safely navigating during the night. This technology has led to vastly increased fish landings (Peña Torres J. 2003).

What about small-scale fishermen? According to the National Confederation for the Defense of Artisanal Fisheries, most members use little technology and are unable to accurately track banks of fish sensitive to changes in temperature, relying instead on time-honored indiscriminate fishing techniques such as longlines and purse seines. To infer suitable fishing zones, some buy seawater temperature charts, others use hull thermometers, while veterans simply use their hands. If they can afford them, shellfish divers use underwater wristwatches, but most simply dive to check temperature conditions prior to starting work. In short, artisanal fishermen are at an enormous disadvantage. While no studies have addressed the technology disconnect, cost seems crucial: a sonar device can cost CLP$15 million (€19,000), an underwater camera some CLP$3 million (€3,800), and multi-parameter, short-range tester probes a similar amount. These are costs that most small fishermen cannot afford. It is also possible that the complexity of instrument operation and maintenance is keeping this user community from enjoying the benefits of technology.

In this scenario, we set out to build an underwater tester probe prototype to evaluate the design, construction and operation of simple, efficient, inexpensive and accurate technologies capable of measuring underwater parameters. Future plans include assessing whether these technologies can help improve output by capturing key data on the range and development of species of commercial value to artisanal fishermen. Our prototype initially focused on physical and chemical parameters such as seawater temperature, crucially important for tracking sensitive marine species. It also focused on shellfish divers, a group with practically no efficient, versatile solutions. These data could help artisanal fishermen become more sustainable and selective by avoiding unwanted catches.

In scientific research, the amount of light penetrating the water, turbidity, conductivity and dissolved oxygen, to name a few, are extremely important marine ecosystem parameters. Knowing them is an important first step toward understanding biological dynamics (Paz F. Wong J. 2013). Designing inexpensive systems to monitor these parameters can encourage research into areas that often exist on the outer boundaries of scientific reach.

We therefore turned to Arduino, a system enjoying growing use for data logging in recent years. Arduino is also popular among students for educational robotics and competitive purposes (Christiansen, Hanna, Agüero, Pereyra 2016), Souza et al 2011, Galeriu, 2013, Galeriu, C. 2014).

Experiences using Arduino systems as deep-water data loggers are found in the literature (Salter, W. The Cave Pearl Project 2011). These show that inexpensive engineering, trial and error, and self-learning can enable testing for physical, chemical and biological parameters in aquatic ecosystems, using data acquisition technologies whose simplicity belies their efficiency.

There is a vast array of low-cost sensors compatible with open-source Arduino and similar systems that enable design of efficient, reliable and upgradeable devices capable of testing for and logging many variables. The C++ programming language used to configure the hardware is easy to understand, requires few commands, and is widely used in schools around the world as an introduction to coding. Systems capable of protecting sensors in extreme environments are also readily available and can be manufactured inexpensively with a modicum of ingenuity, for example using a 3-D printer or recycled parts. To validate our proposal, we field-tested our probe’s ability to withstand expected conditions, perform efficient, accurate tests under most conditions, and gather data equivalent to that obtained by commercial instruments.

These solutions could help improve living conditions in local communities reliant on sensitive marine resources being impacted by the climate crisis and extractive activities. They could also help understand how –or whether- ecosystems are adapting, in an unprecedented partnership between fishermen and academics. We do not refer to financial partnerships but to the two-way scientific collaborative concept known as *citizen science*.

The study of large patterns in nature requires gathering vast amounts of data in a range of locations and habitats over years, even decades, ideally on a daily basis. One way to obtain such data is through citizen science, a research technique that enlists the public in gathering information (Bhattacharjee 2005). Yet, to yield meaningful scientific and educational results, participatory projects require careful planning and affordable instruments. Studies designed to discover species occurrence patterns in time or space are particularly suitable for citizen science (Robbins et al. 1989, Hochachka et al. 2007). For example, it is quite possible for fishermen to supply data of interest to scientists, who in turn can handle data analysis, integration and modelling. The transfer of lessons learned back to the community is an empowering experience that can further sensitize its members to the value of their own environment and inspire involvement in sustainability programs, designed perhaps by the communities themselves rather than imposed by law.

Efficient, inexpensive technologies can have significant commercial and scientific benefits if properly used and managed in a spirit of partnership, cooperation, and understanding. More than ever before, we need sustainable solutions. We have undeniably depended on our oceans since the start of evolution, but we share them with millions of other species. Rather than look for oceans in other planets, we should understand the ones we have.

General Objective

Build an inexpensive tester probe to monitor the water column. The probe should be portable, versatile, accurate, recoverable, and enable retrieval of physical and chemical parameters such as seawater temperature in order to pinpoint areas associated with commercial marine species sensitive to it. The tester probe should also be able to accommodate sensors for conductivity, turbidity, pH, redox potential (as an indicator of chemosynthesis?), dissolved oxygen, fluorescence, and turbulence.

Specific Objectives

- Build a low-cost submersible tester probe designed to take accurate readings.
- Build an Arduino-based electronic system designed to collect temperature data using calibrated, accurate, inexpensive sensors compatible with Arduino boards.
- Store time-stamped data in real time on a micro-SD or similar storage device.
- Attach LCD readout to display real-time data.
- Additionally, test operation of a conductivity sensor.

Materials

- Small fire extinguisher (25 cm x 7.5 cm)
- 8-mm polypropylene line
- O-ring
- 8-wire RJ45 network cable
- 2200-mA cell phone power banks
- Arduino Nano board, DS18B20 thermocouple, clock module, 16 x 2 LCD module, conductivity sensor, SD card reader/writer

Method

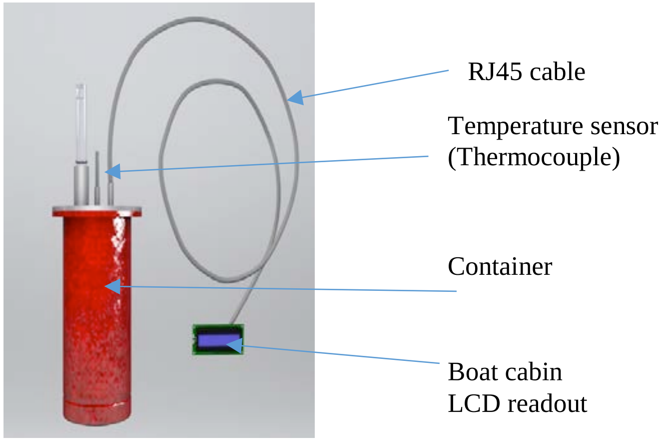

Figure 1. Tester probe and LCD readout.

Prototype 1 was designed and built to test the potential of Arduino boards for logging seawater temperature and conductivity data at depths of 10 m to 300 m. The prototype container was fabricated from a surplus 25 cm x 7.5 cm fire extinguisher (Figs. 1 & 4). Also considered was reuse of steel tubing and other shop and scrapyard discards. For future prototypes, a wide range of easily-modifiable metal sizes, thicknesses, diameters and types can be procured and adapted to any design.

This can help reduce costs and cut down on energy consumption and extra parts, thereby contributing to sustainable development.

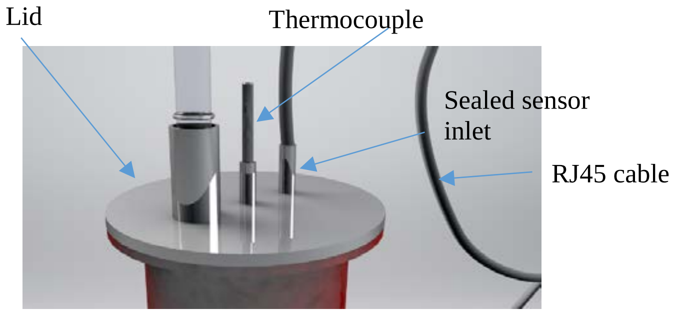

Figure 2. Overview of outlets added to lid in order to fit the RJ45 cable, the temperature sensor (thermocouple), and an optional sensor. This version is waterproofed with an epoxy sealant.

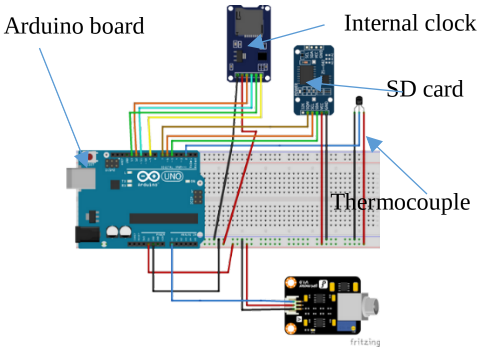

Figure 3. Overview of connections. The electronic circuit was built on an Arduino board and protoboard. For the first testing stage, connector cables and temperature and (optional) conductivity sensors were mounted. Also added was a clock module designed to timestamp the data stored on the SD card. Power was supplied by a 2200-mA power bank providing 30 hours of use. The LCD readout RJ45 cable is connected at the opposite end by 4 wires to 5-volt current, GND, and Arduino board channels A4 and A5.

After removing the fire extinguisher top, a ring-like section was welded on to accommodate a flat metal lid secured by three nuts and bolts (Fig. 4). To prevent water entry, O-rings were also fitted to the lid (Fig. 4). Extra parts were coated with rustproof paint. Mounted in the container were the Arduino Nano processor, the power source, and the clock and SD card modules (Fig. 4) which timestamp and store data for later retrieval. Data files are saved in .txt format and imported into Excel to build charts. Programming is done on a computer in Arduino Sketch software and uploaded to the Arduino Nano through a USB cable. Once powered up, the code executes automatically and runs until the battery is depleted. Temperature and conductivity sensors are exposed to water through openings sealed with epoxy resin (Fig. 2). The container is dropped to the desired depth from a polypropylene line having an attached RJ45 cable carrying a digital signal to an LCD readout (Fig. 1) to display water column data in real time.

Arduino Nano boards and related components are inexpensive (board, temperature sensor, clock module, SD card, LCD readout and power bank can be had for some CLP$60,000 (€76.00). Figures 3 & 5a show electronics powered by a standard cell phone battery recharger linked to the Arduino Nano by USB cable and providing 30 hours' operation. The tester probe was tested for leaks in a swimming pool in Coyhaique, then sensors were tested in the far less controlled environments of nearby rivers and lakes (Figures 6 & 7).

Figure 4. Tester probe prototype 1 showing sensors and waterproofing system details.

Prototype 2 was designed and built based on feedback from artisanal fishermen. This time the main electronics were placed in an external plastic container (a waterproof electrical junction box) except for the temperature sensor, which was encased in a metal tube acting as thermocouple and providing the necessary weight for the tester probe to be dropped to higher depths (Fig. 5b). The thermocouple is secured to the box by a steel cable and a data cable feeding temperature sensor data to the processor. For mechanical and electronic reasons, a cable length of up to 50 m should be viable. In prototype 2 the LCD readout and its data display toggle button are more accessible. In this version the conductivity sensor is removed and power comes from an external source, either a USB port or a boat motor battery.

Results

Sensor electronics and programming became an easy task thanks to the many tutorials available on the internet and the disinterested help of a group of computer science students at the Catholic University of Valparaíso’s Center for New Technologies, to whom we turned at the outset when looking for options. Arduino boards and their open-source programming code are extremely easy to learn and implement. The container, panel and sensors worked generally well in both prototypes and showed no issues during testing in lakes (Figures 6 & 7). Most sensors required no initial calibration and returned values matching those reported by the commercial Hanna HI 98129 tester probe, which attests to both suitability and performance.

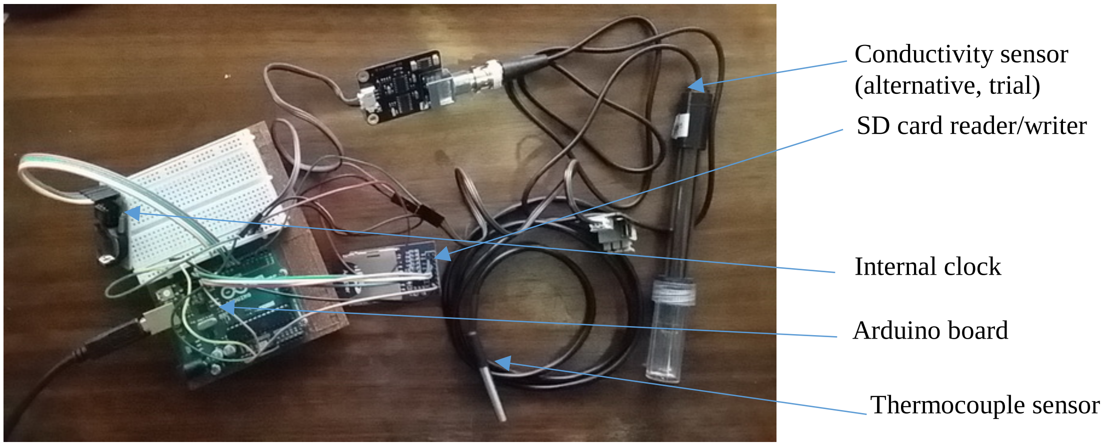

Figure 5a. Arduino electronic components.

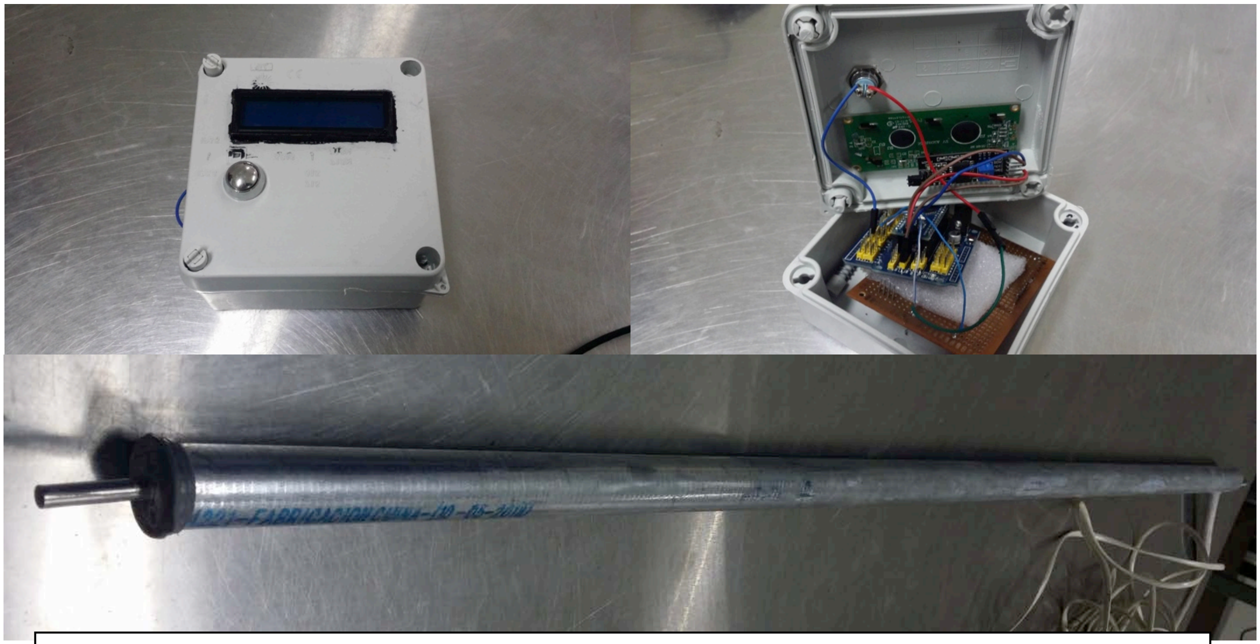

Figure 5b. Prototype 2: External electronics panel containing modules and LCD readout. Temperature sensor is encased in a metal tube secured by steel and data cables.

The cost of sensors and Arduino electronics is extremely low (not more than CLP$60,000 (€76.00) overall) relative to the cost of commercial devices. The container was modified by a local machine shop at a cost of CLP$22,000 (€28.00), for a total of some CLP$80,000 (€100.00). Conductivity sensors cost CLP$33,000 (€42.00) apiece. A commercial tester probe such as the Horiba U52G-10 water quality meter retails for CLP$3,500,000 (€4,462) and works only to a depth of 10 m. True, it can test for up to 10 parameters, but all required sensors are available from the Arduino catalogue –in other words, this comprehensive device can be replicated in full for only CLP$250,000 (€320.00).

Figures 6a and 6b. Testing on the Claro River, Aysén, with strong currents at a depth of 2 m.

According to the manufacturer, the surplus fire extinguisher used to build prototype 1 can withstand pressures of up to 31 atmospheres and thus can easily be dropped to depths of up to 300 m from an 8-mm polypropylene line. The reinforced O-rings used on the lid and the epoxy-sealed sensor outlet tubes worked well to ensure watertightness during tests conducted in Lake O'Higgins, Aysén (Figs. 7a & 7b). The clock module correctly timestamps data at software-controlled intervals; the temperature sensor is accurate and the power banks afford one to two days' service, rendering the probe portable as well as versatile. Retrieving the data card in this prototype can be a bit involved, as removing three tight bolts is not always easy, but the optional LCD readout displays real-time data at all times, provided depth is reasonable and use is limited to one-off field measurements. Data stored on the card can be retrieved every 30 hours of use. The RJ45 cable was not tested beyond a 20 m length, as it is not designed to withstand swift currents and data may degrade as electronic noise increases with cable length. If data from higher depths is

Figures 7a and 7b. Prototype testing to a depth of 300 m in Lake O'Higgins, Aysén.

required, the LCD readout can be removed (as tested at Lake O'Higgins) and card data retrieved at a later time. The tester probe can also be parked from a buoy at medium depth (Fig. 9) and powered by a small solar battery, a configuration that works long enough to record data curves. Prototype 2 has no GPS as the signal does not carry underwater.

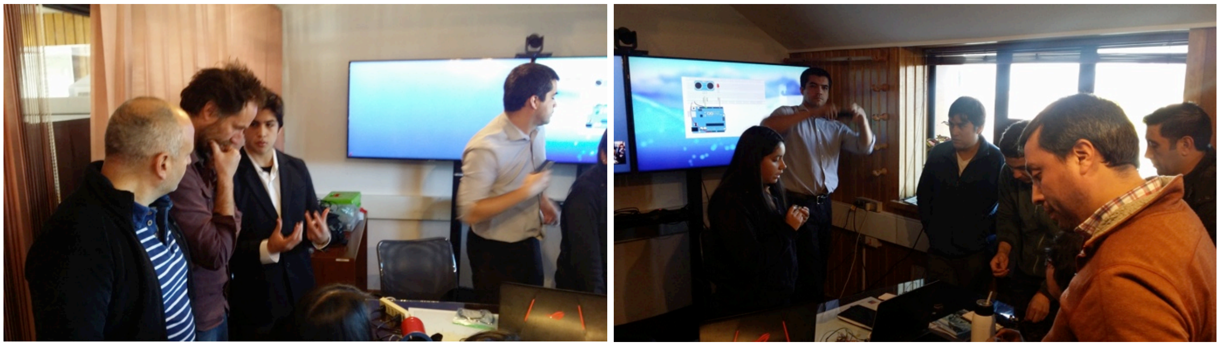

Figure 8. Students leading a training workshop at MOP Aysén.

As testing of prototype 1 proceeded, we realized that fishermen did not need an elaborate contraption equipped with a wide range of sensors. All they needed was to take a reading of seawater temperature to better locate the fish. We therefore designed a second prototype (Fig. 5b) focusing on seawater temperature and offering artisanal fishermen more features, notably a GPS module. Location is important both for fishing purposes and as a complement to data, which is shown on an LCD readout equipped with a button designed to toggle display.

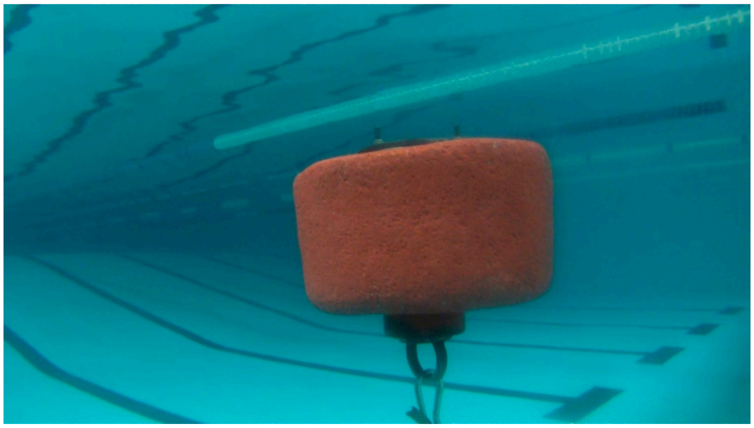

Figure 9. Tester probe in stationary mode, undergoing trials in a swimming pool at a depth of 3 m.

The public interest our tests attracted and several prizes obtained at local science and innovation fairs led to partnerships with key institutions, including the regional office of the Ministry of Public Works of Chile (MOP), whose mandate includes monitoring the country's bodies of water. As a result, we were invited to lead an Arduino training workshop in the regional MOP office (Fig. 8). Those in attendance included hydraulics, buoy and monitoring station specialists who showed us the instruments they use and spoke about their interest in new training and technological expertise with a view to cutting costs or even service electronic equipment in-house. The interest shown by these MOP specialists during the workshop made us realize that if our project impressed trained adults, we could well inspire other people to join us in creating technological solutions based on the open-source concept. As a direct result of the training workshop, we are now working with MOP in validating our data. Another somewhat unexpected result was the response at our own school, where students aged 11-13 have enthusiastically signed on for Arduino workshops (Fig. 10).

Figure 10. Liceo Altos del Mackay students taking Arduino courses.

Analysis and Discussion

Prototype 2 has yet to be tested during fishing actual activities. This version avoids the limits imposed by battery operation, but it does not operate in stationary mode. So far as fishermen are concerned, however, it is lighter, better fitted to their needs, can be powered by a boat motor battery and be operated as just one more piece of onboard equipment.

Affordability and ease of construction helped our prototypes meet with the approval of the local fishermen and divers of Puerto Cisnes, Aysén, who saw it as an indispensable instrument. Dr. Bryan Reid, a researcher with the Center for Patagonia Studies (CIEP) in Coyhaique, agrees with them. Dr. Reid, who works with fixed buoys in lakes and fjords across the region, was one of our science advisors from the start. In his opinion, lower costs can play a key role in encouraging new science and research. Dr. Laura Sánchez, head of the Biodiversity for Aysén and Hongusto projects at the University of Magallanes at Coyhaique, adds that her work is based to no small extent on citizen-contributed data. She notes that the main focus of her projects is advancing participatory science, so that “the citizens of Aysén become protagonists in the generation of knowledge.” “We call it citizen science. We take science out of the classroom and the laboratory and reach out to groups that possess or can seek out valuable knowledge, including students, nature guides and other actors. We aim to build the capacities of all regional practitioners, not just research scientists”. This is what we set out to achieve by supporting artisanal fishermen. Accessible technologies can improve harvest efficiency by pinpointing banks of fish species associated with known temperature ranges, potentially enabling a more selective catch, and the data collected could have significant scientific value. But leveraging this data and conducting more comprehensive monitoring will require new democratic approaches to collaborative research, such as those advanced by Dr. Sánchez and others. The potential benefits seem to us undeniable.

As a royalty-free programming system with a vast catalogue of compatible sensors, the Arduino concept can easily be replicated and improved upon by local student and academic communities. Our results empirically showed that with inexpensive technology and some ingenuity, underwater monitoring is possible. Looking forward, we intend to share these experiences in order to help democratize knowledge through simple technologies adapted to each environment. Our experience with the Public Works Ministry and at our own school made us realize that local communities, especially in remote areas where schools stand within greatly diverse ecosystems that are not easily accessible for scientists, have an enormous research potential. Students wishing to study nearby lakes, rivers or volcanoes or the local atmosphere should have the opportunity and support to explore what remains unknown, sometimes even to scientists. In our own experience, measuring the environment helped us connect with it, and that new connection made us realize the importance of protecting it and of telling others, starting with our parents and our community. Empowerment is the key to caring for the natural environment. This is possible not just for students, but also for fishermen and the rest of the community. As a direct result of our project, we are now working on a cooperative program with schools throughout Aysén which includes workshops and visiting other students to speak about our experience and promote interest in the local environment. We hope to obtain support from universities or public institutions.

Benefits could not be community-validated at this stage of the project. This will require a long-term effort working with fishing, academic and educational communities and the commitment of all concerned to disseminate and promote these benefits at no cost and in a disinterested manner.

Conclusions

Affordable technologies such as what we devised are crucial for exploration of ocean environments. Yet, where the resulting data could be most helpful in addressing sustainability and the connection of local communities to marine ecosystems is in the livelihood activities on which so many communities depend.

Our tester probe prototypes met most of the stated objectives, including reading, recording and storing data that was both reliable and accurate. Both versions were portable and easy to handle in marine environments and both were very inexpensive compared to commercial alternatives.

Our prototypes could read multiple parameters thanks to a vast assortment of Arduino-compatible, commercially available sensors. Our tests further showed that conductivity sensors are fully functional under the stated conditions, and initial testing of turbidity and turbulence sensors is now underway. With this we hope to encourage others to ask new questions, formulate new hypotheses and come up with new ways of working with citizens. Artisanal fishing communities, for example, can join with students to do citizen science and democratize knowledge. Innovative, inexpensive and inspirational technologies can improve productivity, sustainability and local living conditions and ensure a new connection with the environment, especially among young people.

Evaluating and validating whether inexpensive monitoring systems can be widely adopted, thereby helping promote sound fisheries management and cooperation between academia and the community, was not part of our study. Disseminating and promoting these benefits will require a long-term effort and the commitment of all concerned.

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