Opportunities for marine aquaculture to meet the Aquaculture Imperative

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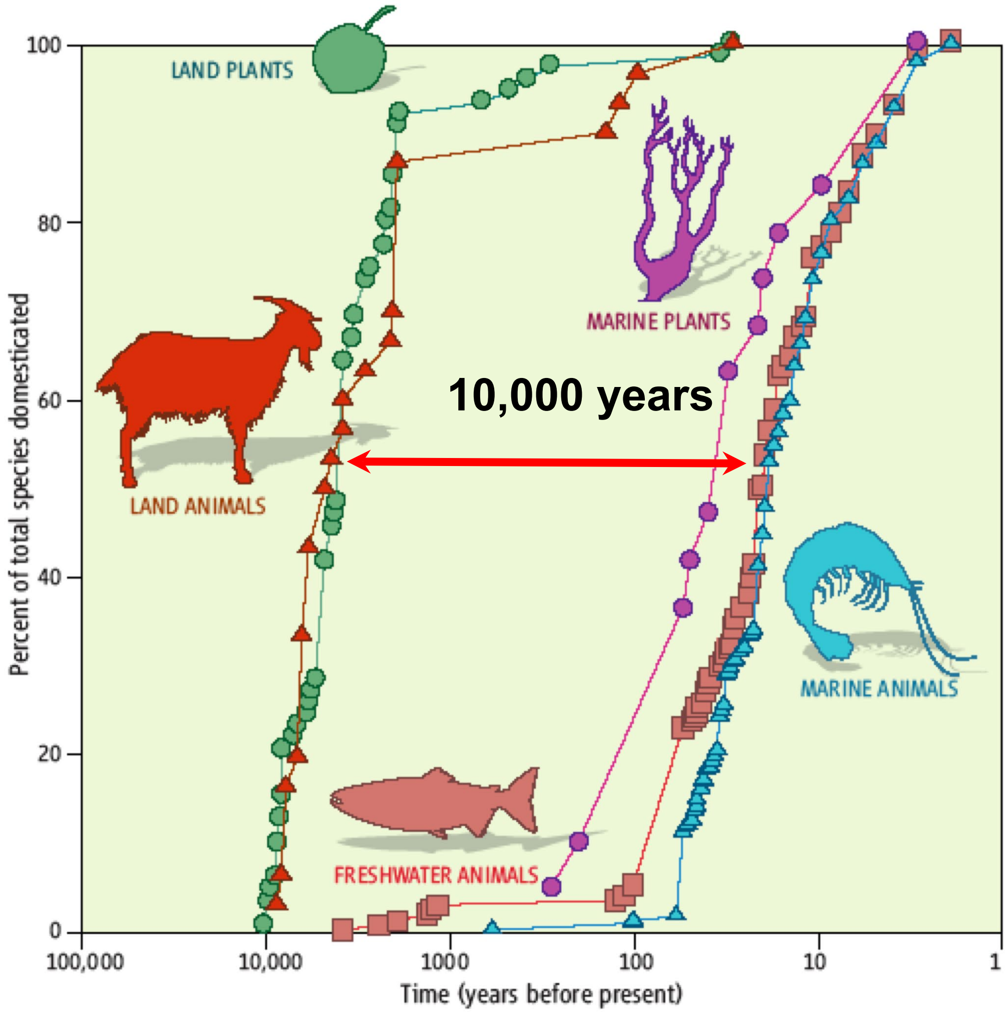
Science for Ocean Actions

Bergen 20-21 November, 2018

Aquaculture started about 4,000 years ago – independently in China and Egypt - with the domestication of freshwater carp and fattening of marine fish held in captivity.

Only in the 2nd half of the 20th Century did humans developed the capacity to rear and domesticate marine animals, 10,000 years after this was achieved on land



Industrial Aquaculture is a recent phenomenon, starting in the 1970's with approaches rooted in the 2nd industrial revolution

(e.g. the contemporary technique of rearing salmons in sea cages originated in Norway in the late 1960's)

Duarte et al., Science (2007)

“Marine Aquaculture” first used in a scientific paper in 1969

Total Publications

1,421 Analyze

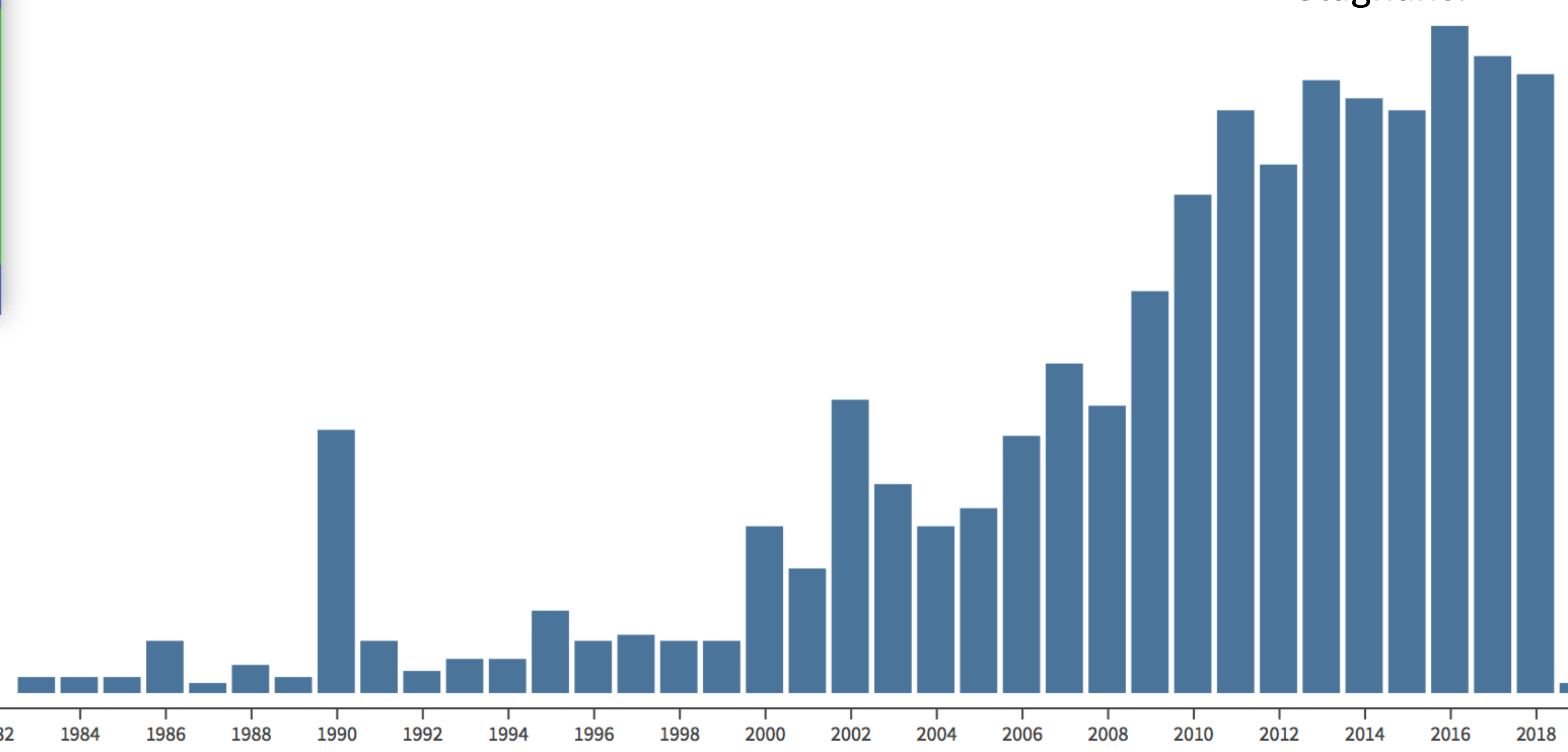
Started in 1972

RESEARCH IN MARINE AQUACULTURE AT INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF MIAMI

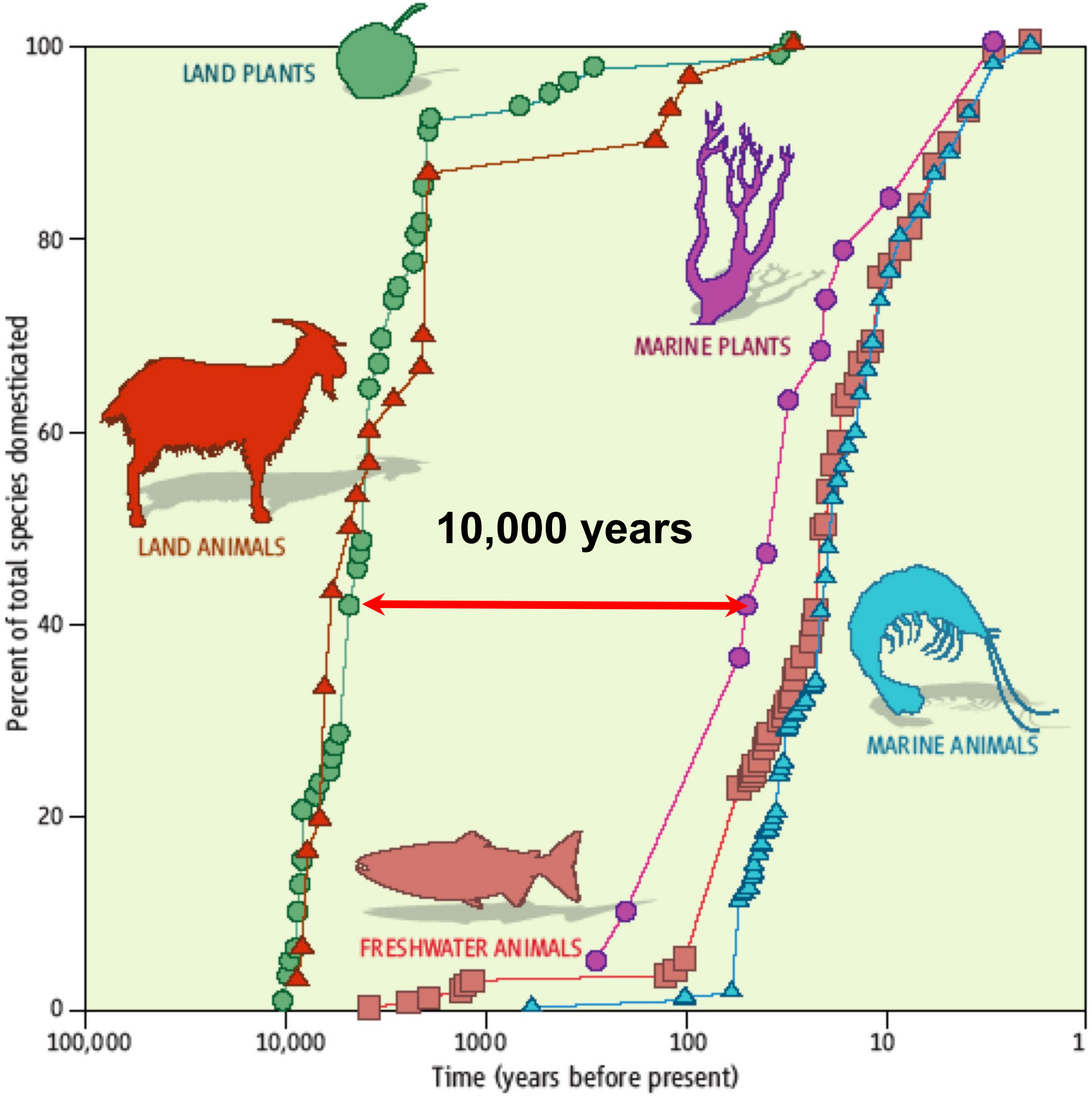
By: TABB, DC (TABB, DC); YANG, WT (YANG, WT); IDYLL, CP (IDYLL, CP); IVERSEN, ES (IVERSEN, ES)

TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Volume: 98 **Issue:** 4 **Pages:** 738-&

Stagnant?



Rapid Domestication of Marine Species



One in every thousand marine animals already domesticated, compared to 1 in every 100,000 land animals.

About 10 new marine species are domesticated each year.

Duarte et al., Science (2007)

The new kid on the aquaculture block

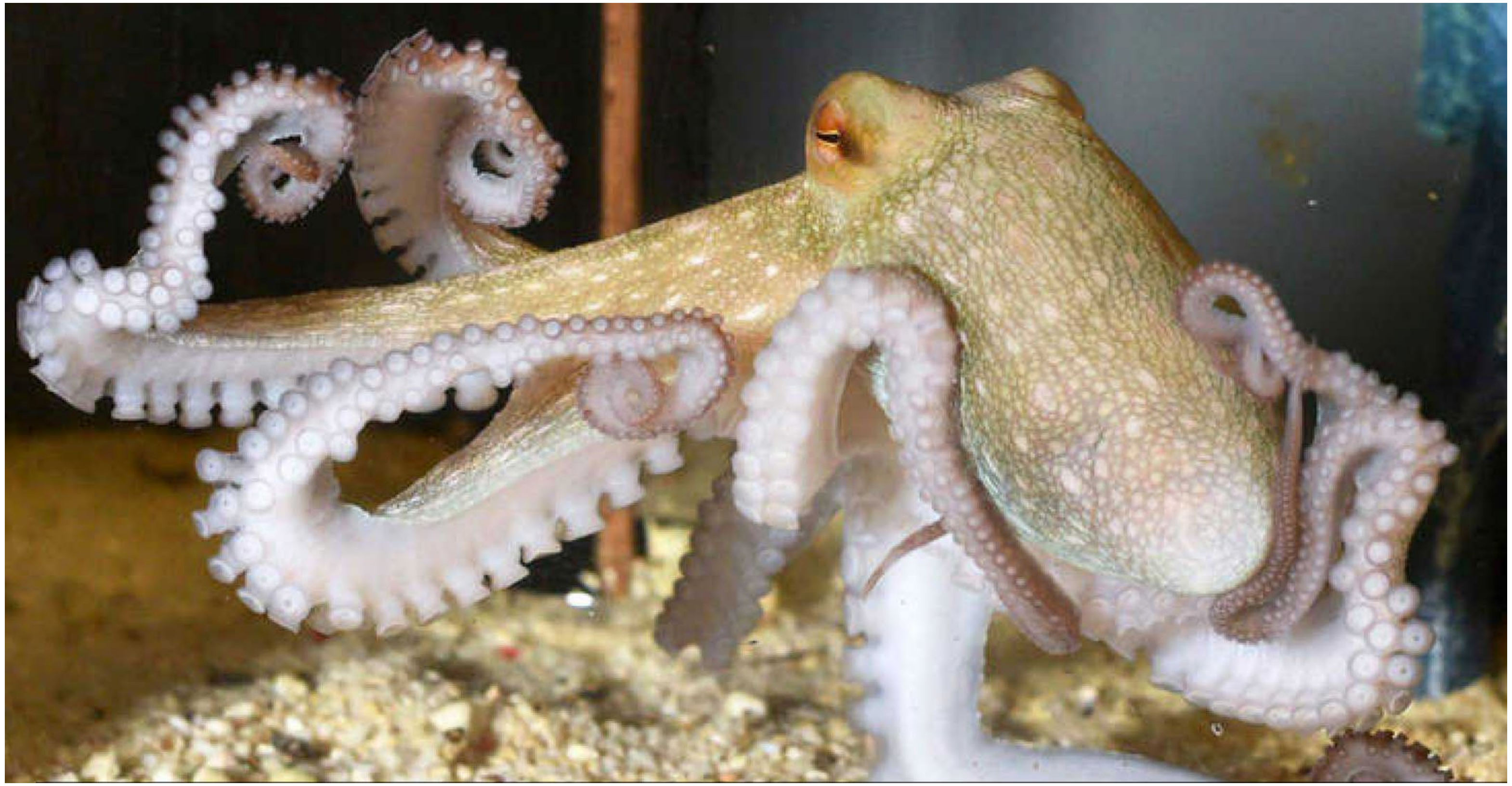
≡ EL PAÍS GALICIA

ANDALUCÍA CATALUÑA C. VALENCIANA GALICIA MADRID PAÍS VASCO MÁS COMUNIDADES TITULARES »

- 8 NOV 2018 -

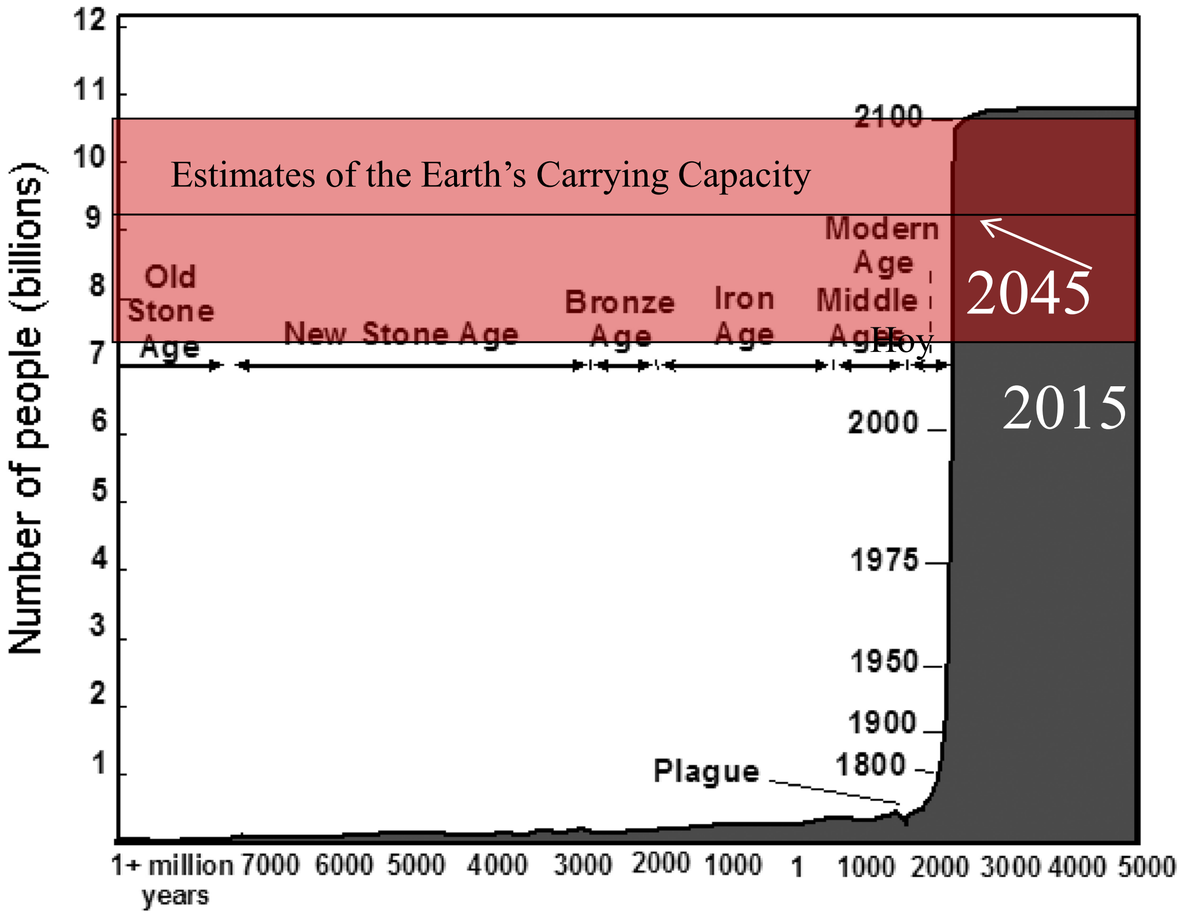
Científicos de Vigo logran la reproducción del pulpo en cautividad después de 20 años

New diet succeeds in overcoming
The metamorphosis bottleneck



Beyond a business:
A key role for marine aquaculture in the future of humanity

Human Population Growth about to meet the planetary limits



Data Pop. Ref. Bureau y de NU

Water
Arable land
Food

Crop area declined from 0.5 to 0.25 ha/capita 1960 and 2000 (CAWMA 2007),

Humanity is about to enter a new period of limited Earth's capacity to support further population growth

Water consumption with food

Subsistence diet: 1 m^3/cap day

Vegetarian diet: 2.6 m^3/cap day

USA diet: 5 m^3/cap day

Renewable freshwater ~ 40,000 $Km^3\ yr^{-1}$

Available freshwater ~ 9,000 - 14,000 $Km^3\ yr^{-1}$

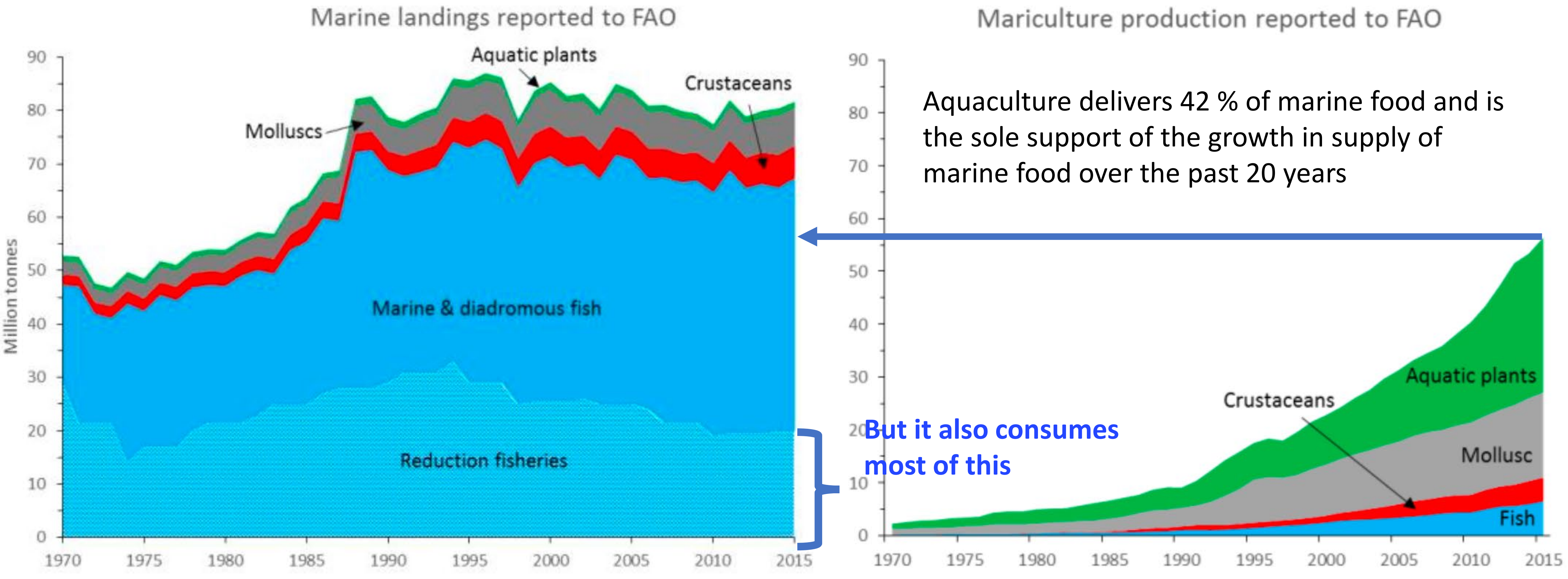
Minimum per capita water use ~ 900 $m^3\ person^{-1}\ yr^{-1}$

Maximum population
that can be supported ~ 8,000 - 12,000 million

Cohen (1995), FAO (2006)

The Marine Aquaculture Imperative:

The sole sector capable of increasing food production to the required levels at the required speed



SAPEA Food From Oceans report (2017)

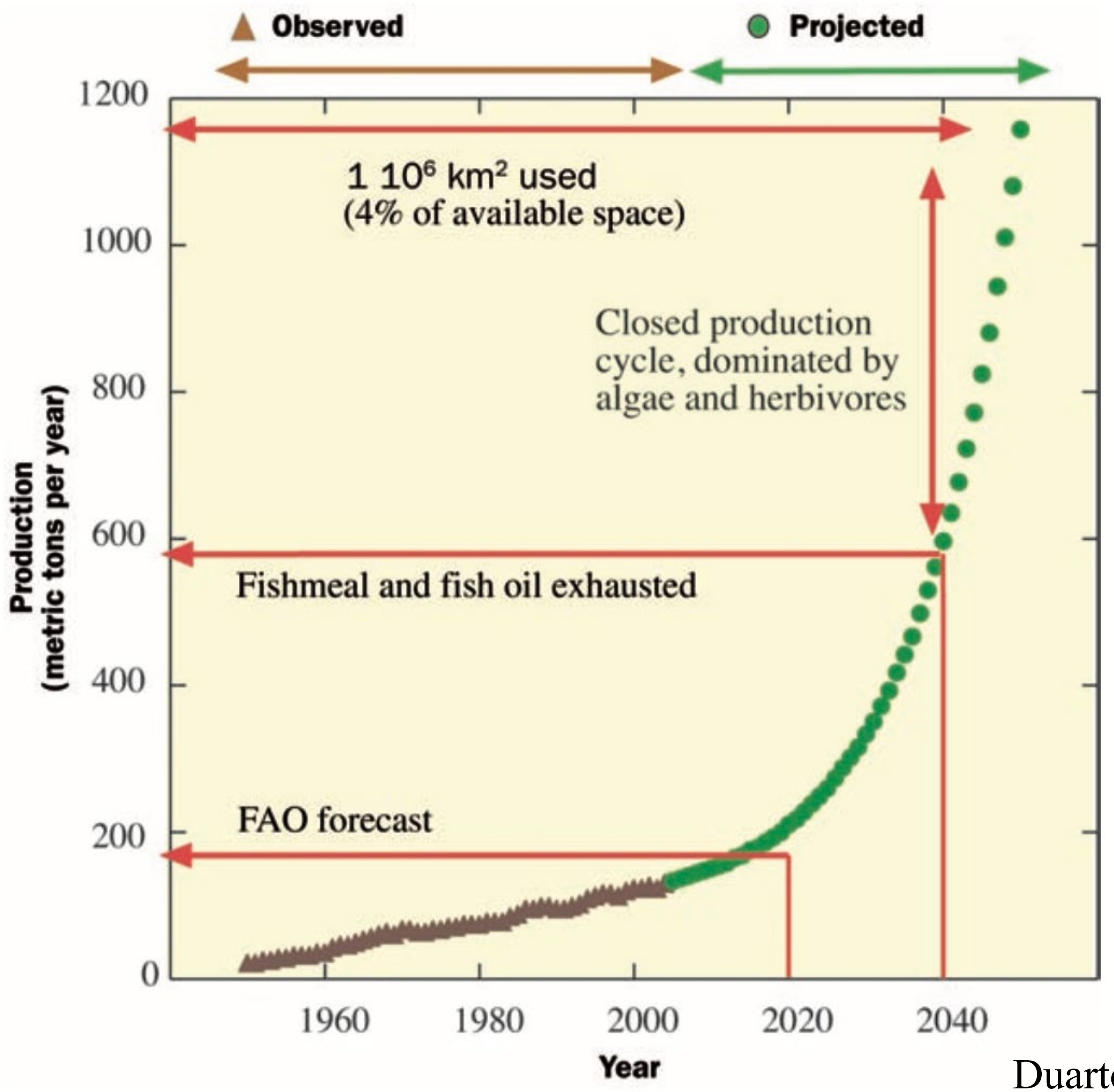
Health benefits to humans of marine-based diet

Evidence of n-3 HUFA Benefits on Health
Cardio vascular diseases (Dyerberg et al., 1975)
Asthma (Broughton et al., 1997),
Rheumatoid arthritis (Calder and Zurier, 2001)
Alzheimer's disease (Morris et al. 2003),
Crohn's disease (Belluzzi and Miglio, 1998)
Lupus (Kelley et al. 1985)
Cancer (Hardman, 2002)
Diabetes (Lombardo and Chicco, 2006),
Psoriasis (Ziboh, 1988)
Schizophrenia (Peet et al. 2001)
Bipolar disorder (Noaghiul and Hibbeln, 2003)
Autism (Bell et al. 2004b)

from Bell and Waagbø (2010)

Omega 3
Iodine
Lithium
others

Scope for Future Growth



Challenges Abound

- **Dependence on wild catches for feed unsustainable.**
- **Dependence on land agriculture for feed also unsustainable as it will lead aquaculture to compete with crops for land and water**
- **Most fish aquaculture practices generate impacts on the environment and wild stocks** (organic pollution, disease risk, escapees, antibiotics and other chemicals).
- **Introduction of genetically-modified animals risky and unnecessary.**
- **Competition for space with other users of the marine space.**
- **Negative perception by the public**

Duarte et al. (2009)

Global Conversation on Aquaculture Yesterday

Aquaculture Therapeutics Market Pegged for Robust Expansion During 2016-2026

Just more anti-aquaculture propaganda

November 19, 2018 on Commentary, Opinion

SUSTAINABILITY

Improved Husbandry Practices Boosts Aquaculture in Kenya

Aquaculture key to food security and nutrition?

Norway's approach to fisheries and aquaculture management

Quality over quantity: climate change affects volume, but not quality of aquaculture

Climate Change Looms as a Long-Term Threat to Aquaculture

Cage aquaculture offers fresh hope to marine fish farmers

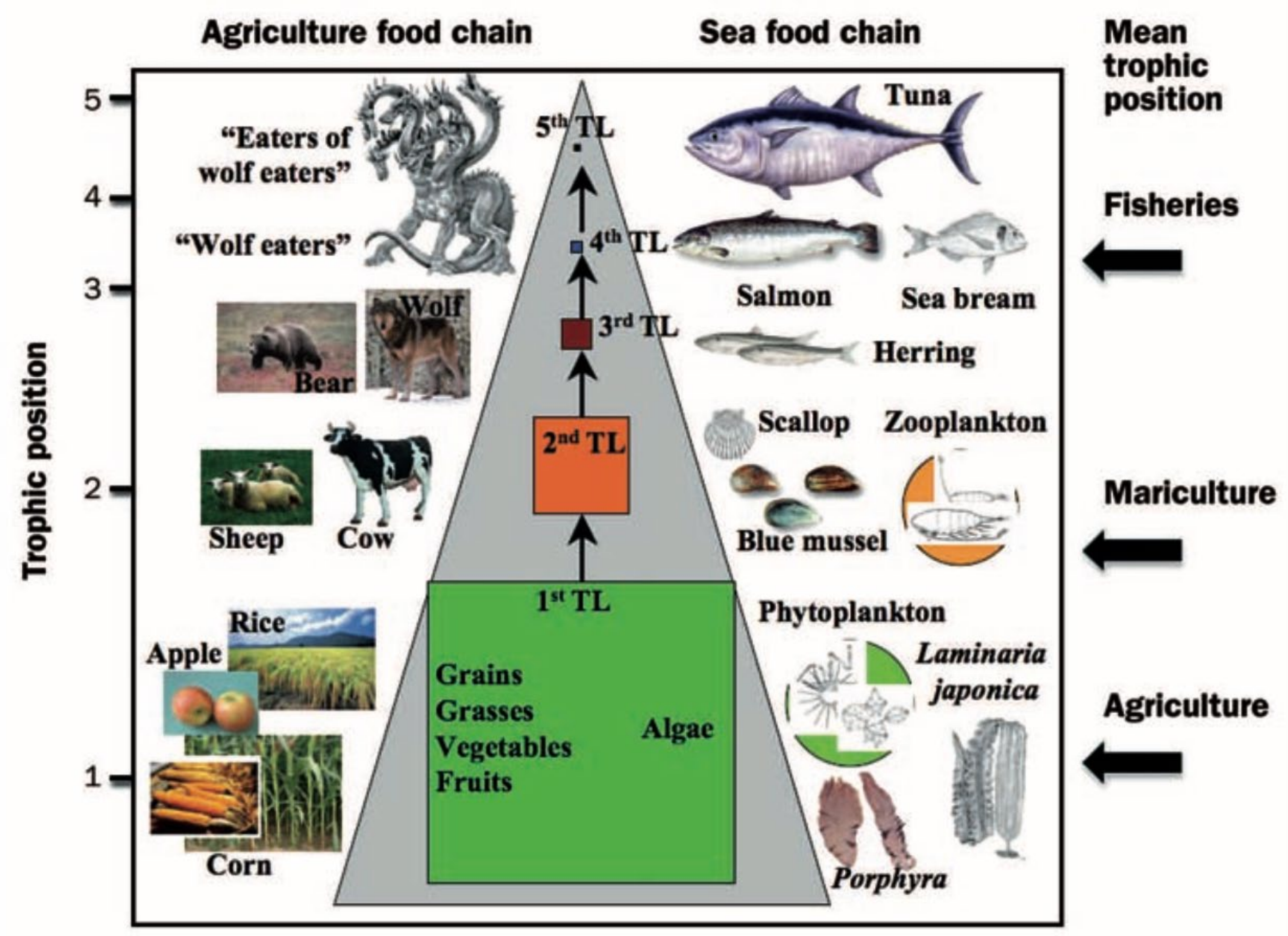


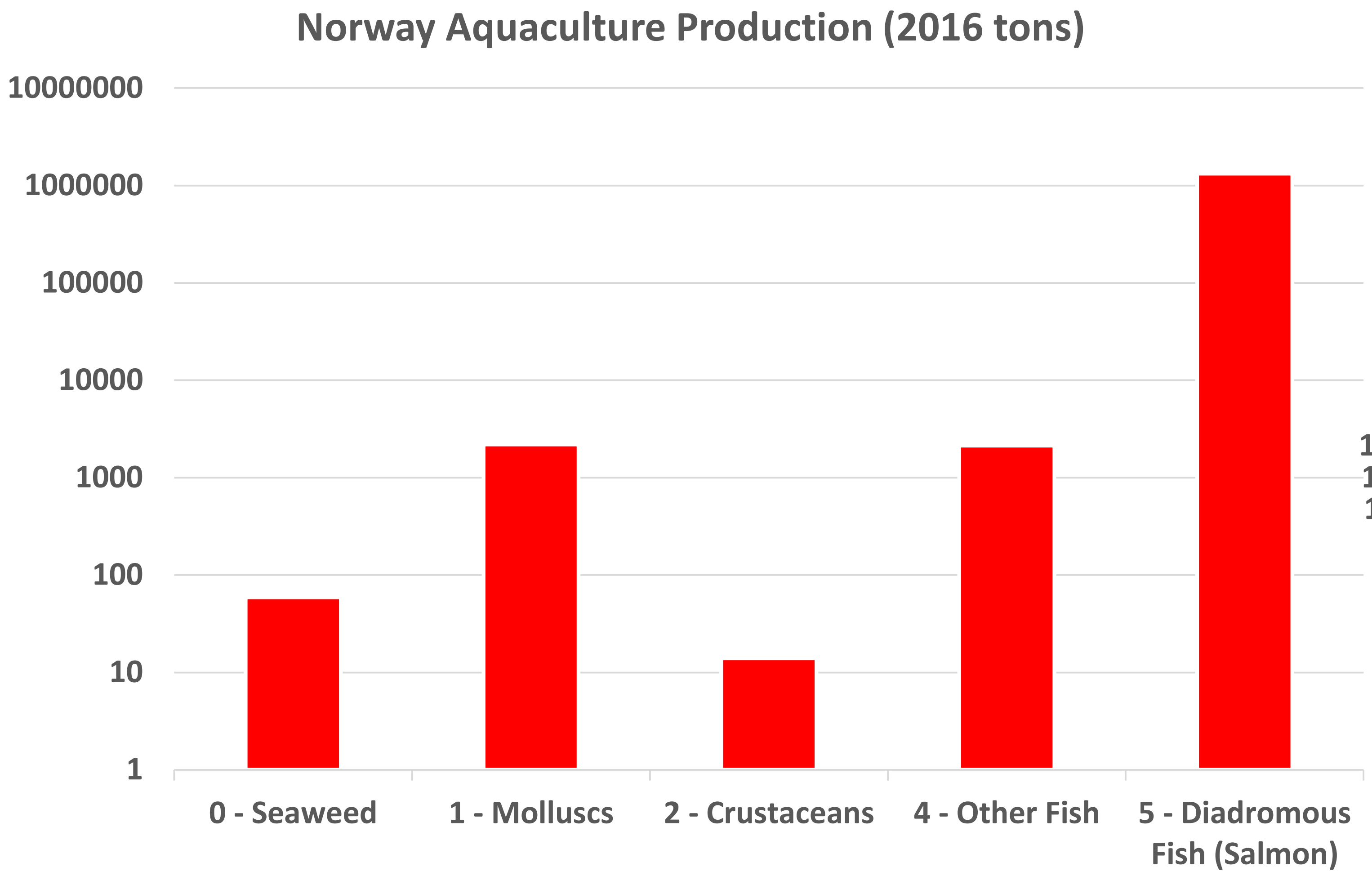
Figure 4. A comparison of the trophic position of agriculture and mariculture products, including idealized parallels of terrestrial equivalents to high trophic positions harvested at sea, along with the weighted-mean trophic position of wild fisheries, mariculture, and agriculture products (see table 3). Abbreviation: TL, trophic level.

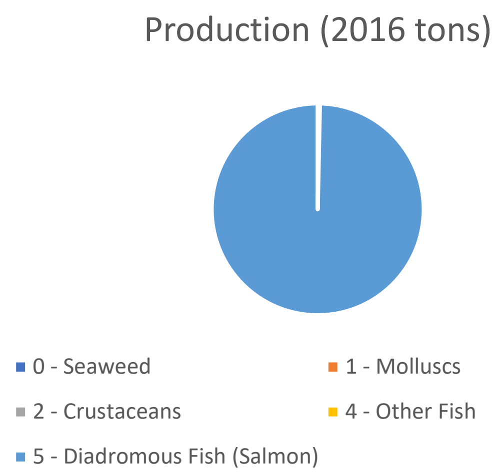
But Solutions are known:

- **Close the production and recycling cycle (multitrophic aquaculture)**
- **Lower the exploitation trophic level (seaweed, herbivores, filter feeders and detritus feeders).**
- **Use "sustainable aquaculture" certification systems.**
- **Use smart Marine Spatial Planning to designate suitable areas for aquaculture.**
- **Develop regulatory environments that drive industry away from environmental impacts and provide incentives for positive environmental impact.**

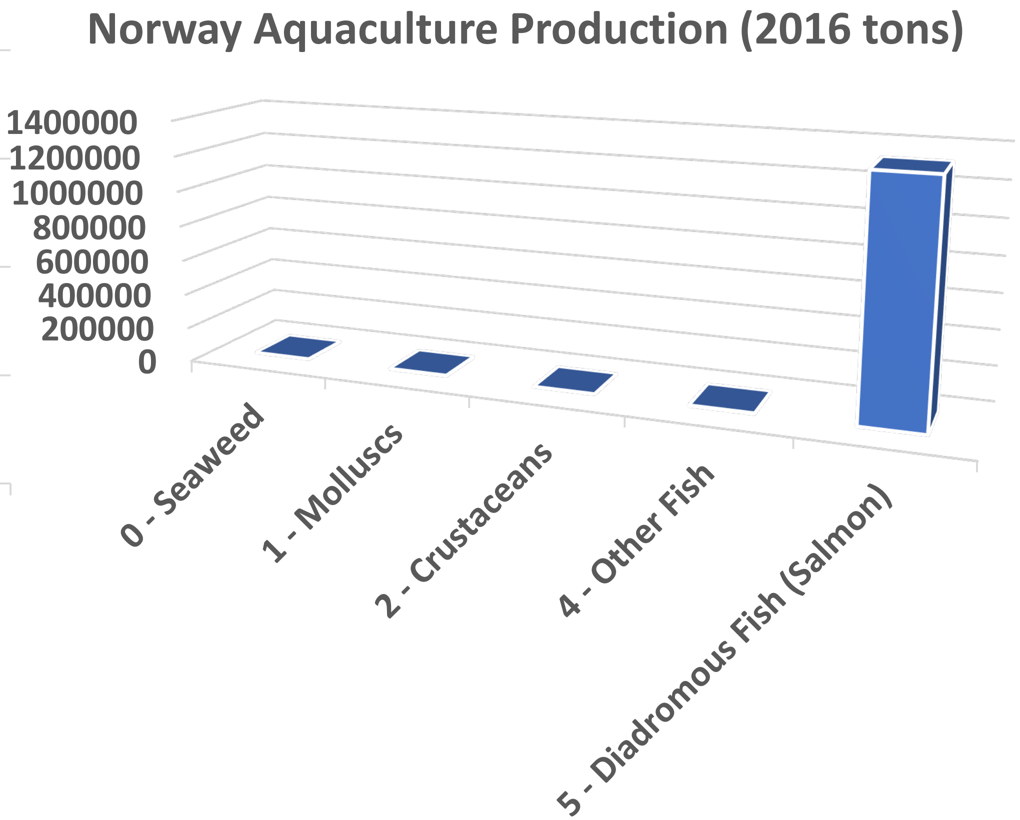
Duarte et al. (2009)

The up-side down Norwegian Aquaculture Food Web



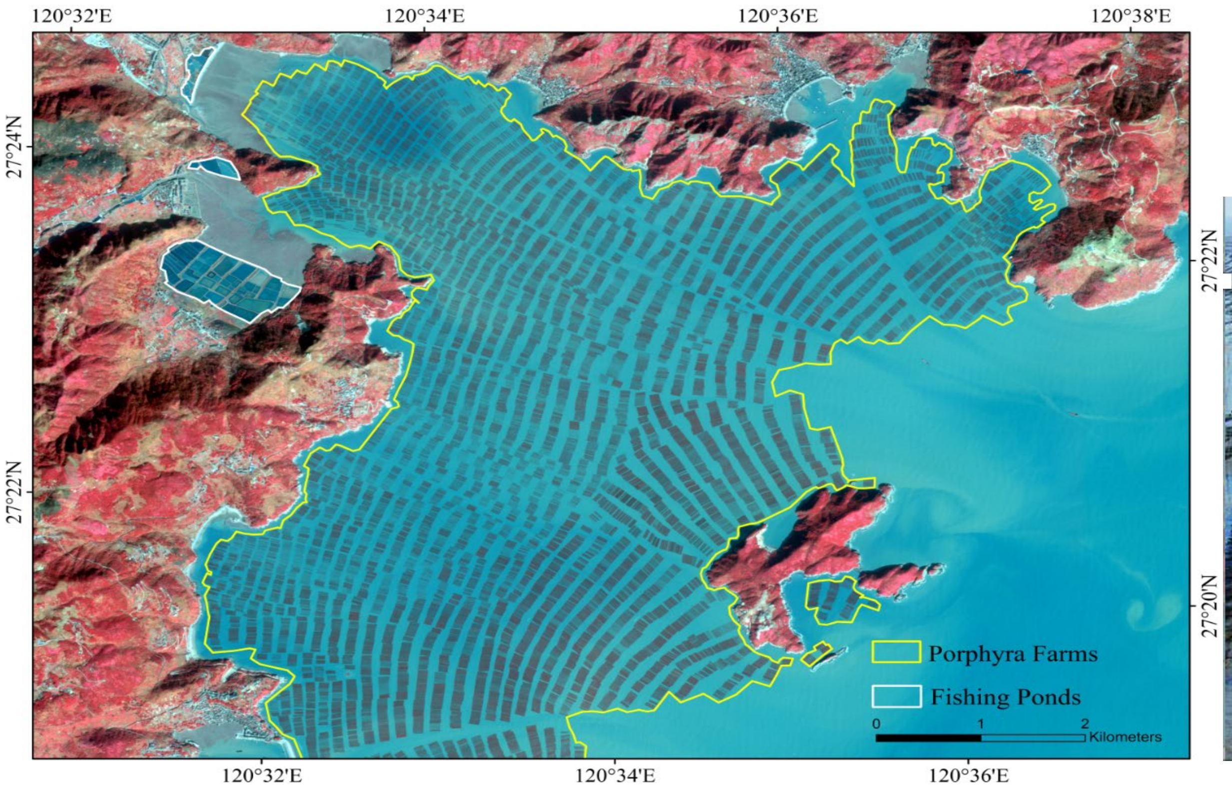


A Salmon Monoculture (high risk)



e.g. Abalone (*Haliotis sp.*) culture (herbivore, high value)

Large-scale seaweed aquaculture in China



Low footprint in the environment compared to land-based agriculture

Aquaculture does not require:

- Arable land
- Freshwater
- Fertilizer
- Herbicides/pesticide

SEAWEED FARMING AND CLIMATE CHANGE

MITIGATION VIA:

Ongoing processes:

Food production
with reduced CO_2 foot print

C-sequestration
via export of “unseen” production

Future potentials:

Bioenergy production
substituting fossil fuels

Reduction of methane emission
via seaweed feed additive to ruminants

Stimulation of land-based production
via seaweed biochar soil amelioration & seaweed prebiotic health benefits to livestock

Climate benefit of circular nutrient management
Via avoidance of CO_2 emissions for synthetic fertiliser production

ADAPTATION TO:

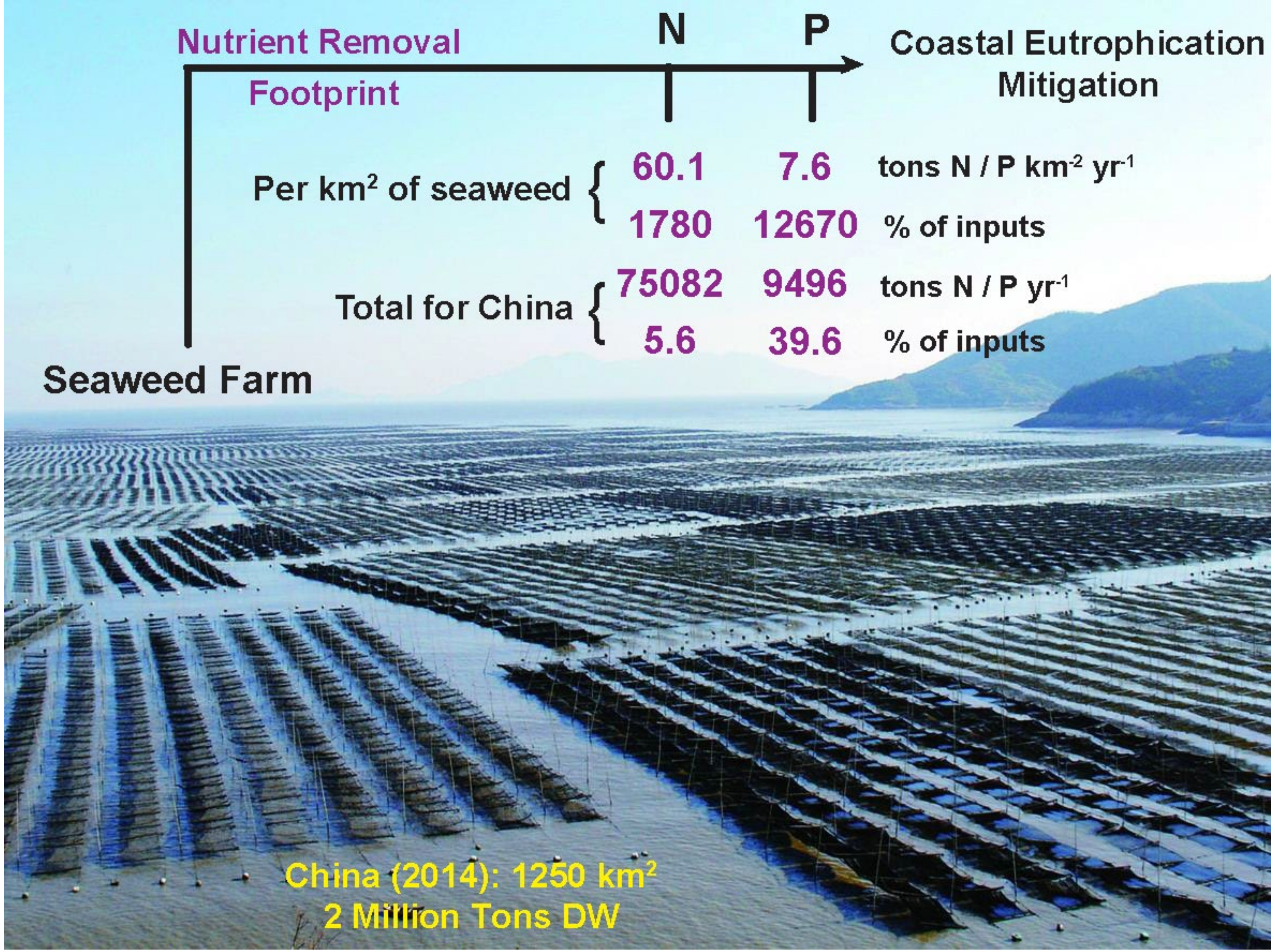
Ocean Acidification
High daytime pH in seaweed to the benefit of calcifiers

Increased storminess and sea level rise
Shoreline protection via dissipation of wave energy

Oxygen inputs to coastal waters
Avoiding ocean deoxygenation with warming

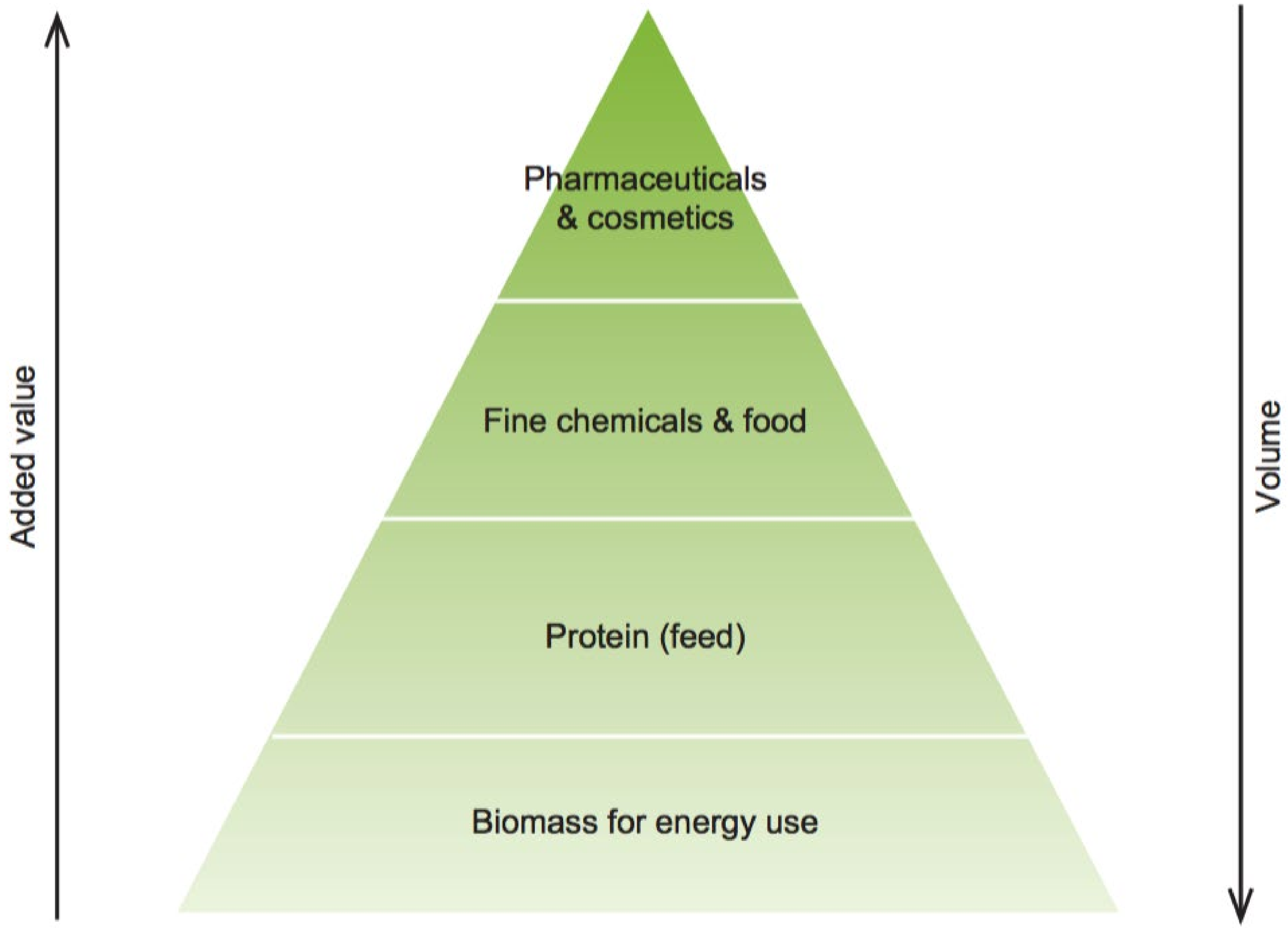
Duarte et al. (2017)

Eutrophication alleviation by Chinese seaweed aquaculture



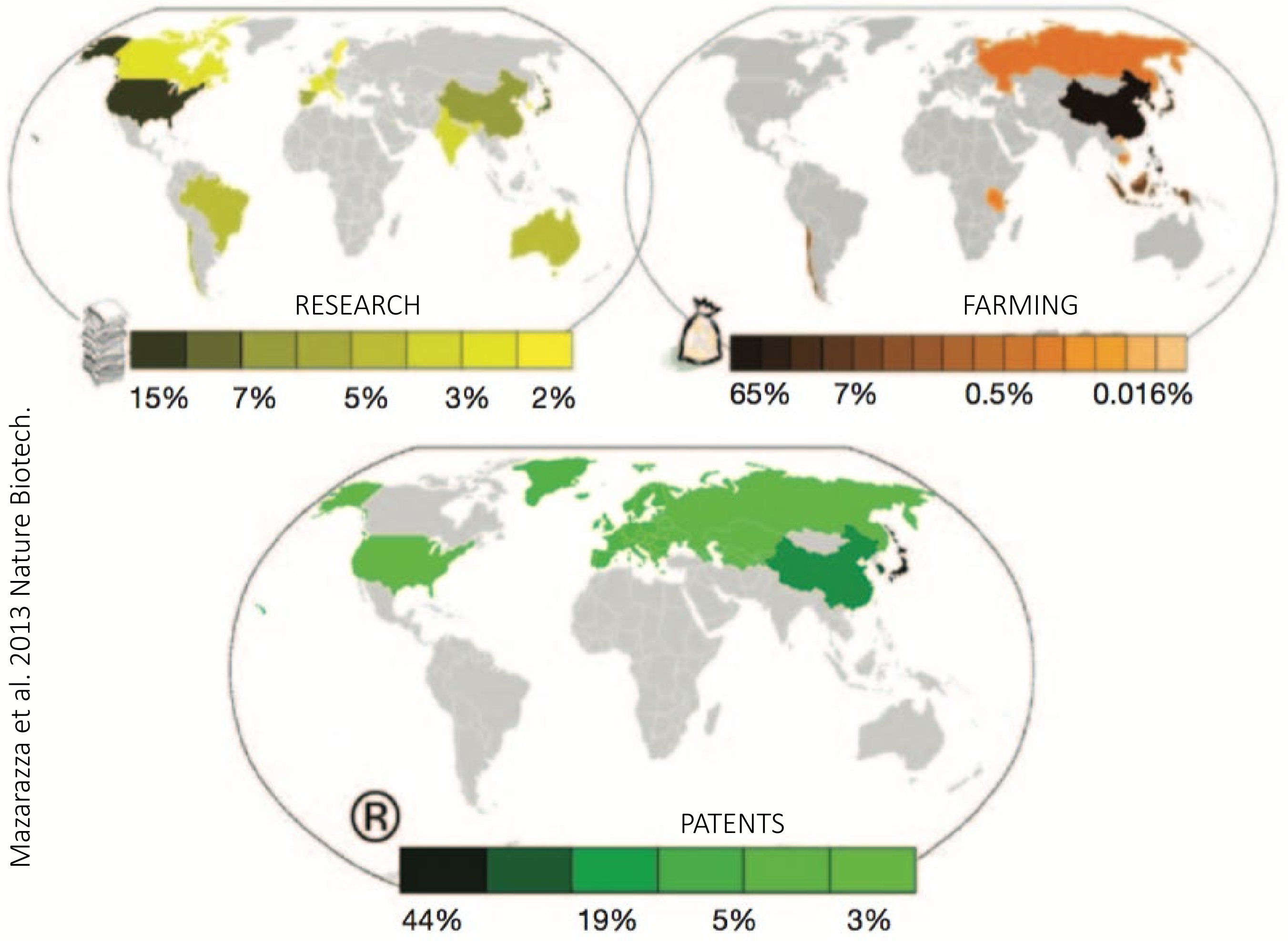
Xiao et al. (2017)

Maximizing seaweed benefits - BIOREFINING



Nielsen et al. 2015 (based on Bruton et al. 2009)

Disjoint global distribution of aquaculture (e.g. seaweed) innovation and production



Mazarazza et al. 2013 Nature Biotech.

Most patents in countries that have both research and production

Huge Opportunities for Aquaculture

Diversify the market for aquaculture products:
High-value chemicals (supercritical extraction: pharmaceuticals, nutrition supplements, others)
Biofuels
Building and insulation materials
Marine polymers (replacement for single use plastic?) and other use of seaweed materials

Extend offshore (new engineering concepts and technology)

Fully realize its potential to be a positive force in the environment:

- Eutrophication alleviation (e.g. large role in China)
- Climate change mitigation and adaptation
- Rearing and release of animals to help recover stocks, conserve endangered species (already applied for some shark and seahorse species)

Why China is a hub for building offshore aquaculture pens

By Louis Harkell Oct. 2, 2018 09:13 GMT

SalMar's Ocean Farm 1 under construction in Qingdao, China. Credit: People's Daily

"The facility is fully automated with normal operation requiring a crew of just 3 – 4 people".
"It can also be remotely operated."

- Heavily Robotized
- Heavily Digitized ("the internet of things")
- Remotely Operated
- Supporting and Supported by Biotechnology

Aquaculture meets the 4th Industrial Revolution!
(jumping over the 3rd!)

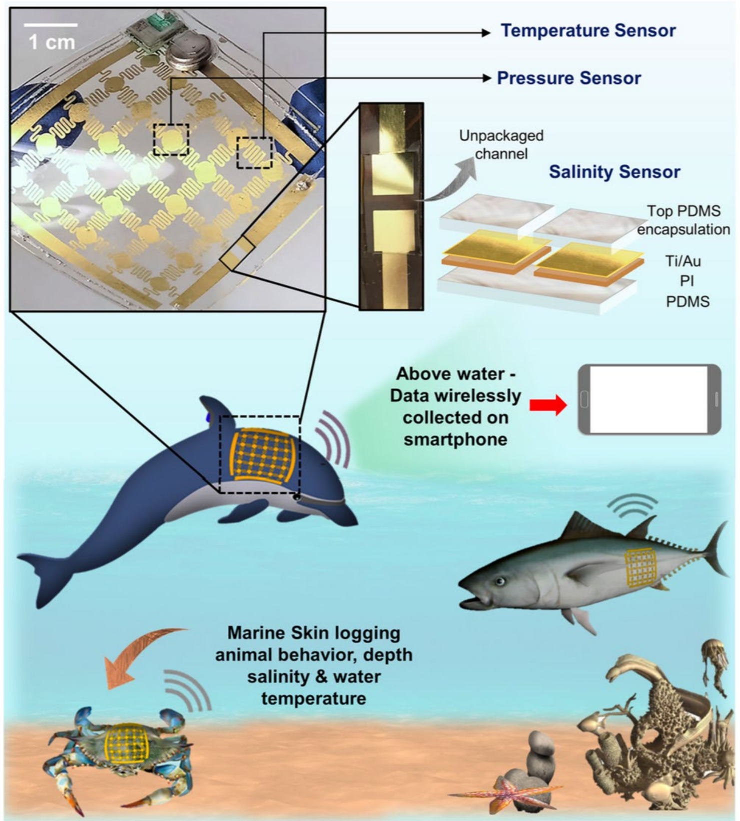
npj Flexible Electronics
www.nature.com/npjflexelectron

Last paper published (May 3, 2018)

ARTICLE OPEN

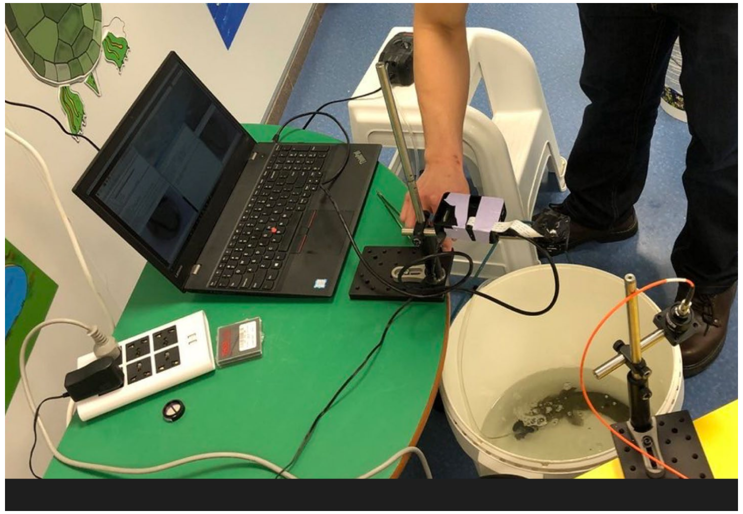
Compliant lightweight non-invasive standalone "Marine Skin" tagging system

Joanna M. Nassar[1], Sherjeel M. Khan[1], Seneca J. Velling[1,2], Andrea Diaz-Gaxiola[1], Sohail F. Shaikh[1], Nathan R. Geraldi[3], Galo A. Torres Sevilla[1], Carlos M. Duarte[3] and Muhammad M. Hussain[1]



The Internet of Marine Beings

Sensors to monitor behavior



Sensors to monitor behavior

Aquaculture to-do list

- 1. Transform Aquaculture into a Sustainable, Technology-savvy Industry and develop partnerships between research intensive and research-poor nations to accelerate innovations.
- 2. Deliver its full potential to be a positive force contributing to improved ocean (and human!) health and acknowledge this both in the regulatory and incentive (e.g. tax deductions, payment for environmental services) systems
- 3. Manage public perceptions to address paradoxes (e.g. 2/3'S of land transformed but 0.01 % of ocean used a problem) and misconceptions.
- 4. Develop a regulatory environment that propels, rather than inhibit, the growth of aquaculture and its transition into the 4th Industrial Revolution.

Industry, Government, Int. Cooperation, Research & Technology