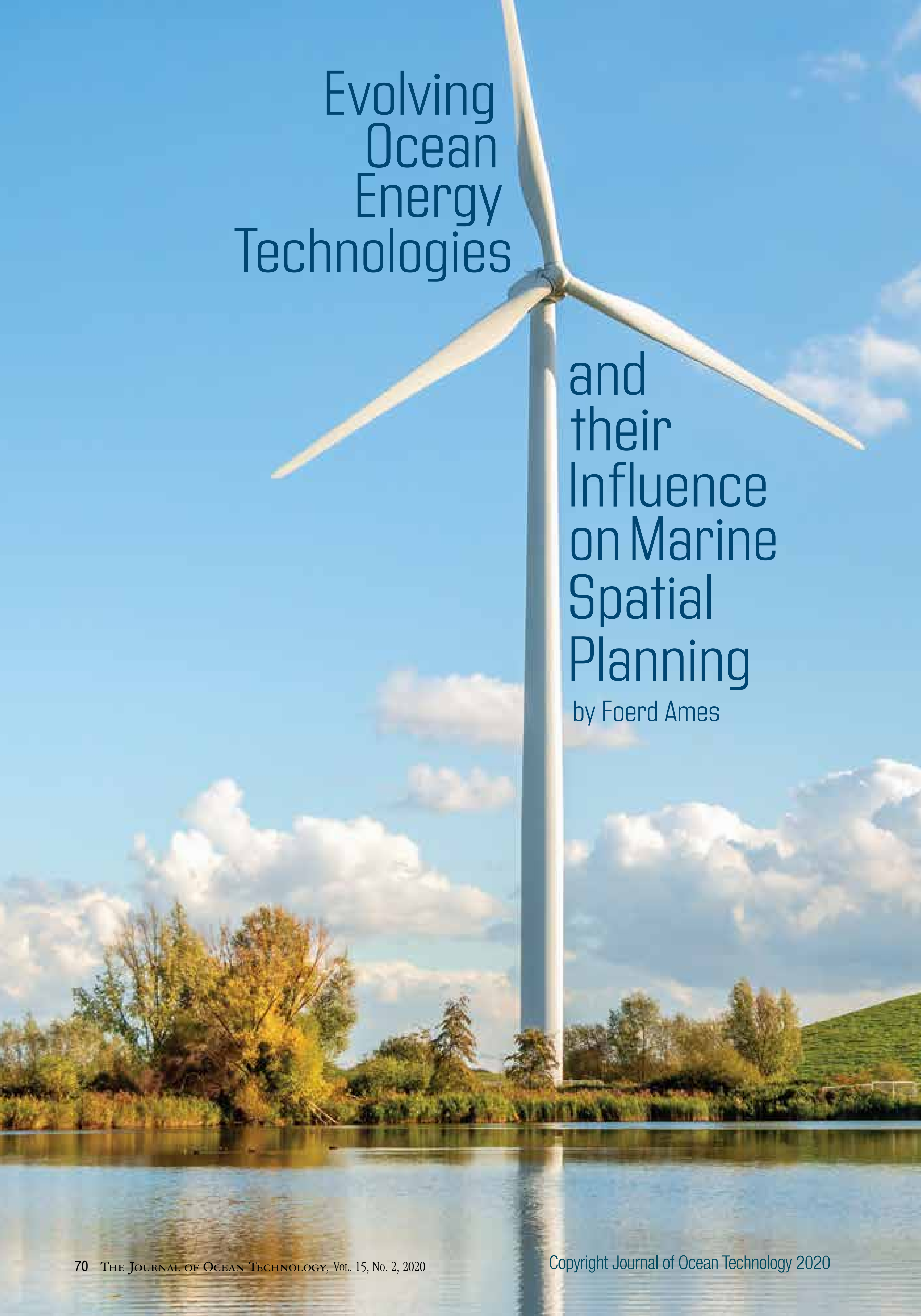

Evolving Ocean Energy Technologies and their Influence on Marine Spatial Planning

by Foerd Ames

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Introduction

On shore, offshore, and floating solar or wind electrical generation has been successfully demonstrated globally and is reaching for large-scale utility. Marine hydrokinetics (MHK), however, from ocean currents, salinity and thermal gradients, tides, and waves remain mostly untapped. Their dense energy but diffuse nature requires distributed systems of connected modules operating in harsh environments. Small quantity deployments provide electricity for aids to navigation, monitoring equipment, sustainable mariculture, and offshore operations. Saving precious land, more numerous connected module arrays can help to electrify islands, conventionally energy deficient regions, and off-grid applications. Several countries and islands have abundant marine renewable energy resources that greatly exceed local power needs. Some of their landfall and numerous seamounts support ocean energy operations. Coasts and shoals accommodate MHK device staging, servicing, and power equipment. Other highly populated continental areas have relatively low renewable power generation availability. Remotely produced energy must be conveyed to where it is needed. With fewer zoning consent issues than land-based renewables, marine hydrokinetic energy module arrays can directly transmit high density power through wire to existing coastal electric grid transfer stations and mainland population centres. The marine hydrokinetics industry is bound to deploy a larger quantity of modular structures at deeper sites.

Special wave energy converter (WEC) modules use wave energy to pump down oxygen to depths that stimulate web of life near ocean dead zones. Bio-compatible structural materials and coatings tolerate bio-growths without impeding mechanical functions. Shade-casting framing structures and lee side wave attenuation promote symbiotic habitat restoration. Most WEC developers aspire to technologies having least natural disturbance and true cost.

Marine Spatial Planning

Marine spatial planning (MSP) is an essential component to identify preferable deployment sites and, importantly, areas where large networks of renewable ocean energy systems should not be installed. Government-sponsored wave hubs bestow the young industry minimal footprint platforms and anchorage for organized, comparative WEC device testing. MSP intrinsically evolves with continual environmental impact assessments before, during, and after project performance periods. Similar to existing conditions and site plan drawings that precede architectural construction, pre-project deployment site MSP can administer baseline analytical templates from which future change can be referenced. Google Earth digital twin (a virtual representation) bridges marine spatial planning virtual simulation models and real world objects. The commonly used platform is a template to coalesce geospatial data from several sources. Most national waters, ship routes, cetacean and mammalian routes, habitats, coral reefs, marine protected areas (MPA), and other identified sites are initially excluded from marine hydrokinetics siting consideration. Polar sea-ice drift and subsurface currents are also significant avoidance factors. Integration of real-time 3D marine spatial observers would improve global water column comprehension.

Bio-compatible MHK modules can be serially connected as navigation barriers between MPA margins, shipping lanes, and other human activity. Adaptable module arrays are able to be re-arranged in numerous configurations to comply with changing conditions. Spatial planning reveals that the extensive works of existing coastal power grid infrastructures, where most humanity lives, need relatively little modification to accommodate a globally connected ocean renewable electric and gas network (Figure 1). Yet, continuous, amendable planning and technology implementation must be accelerated to manage rapid climate change effects. Substantial activity is required to install

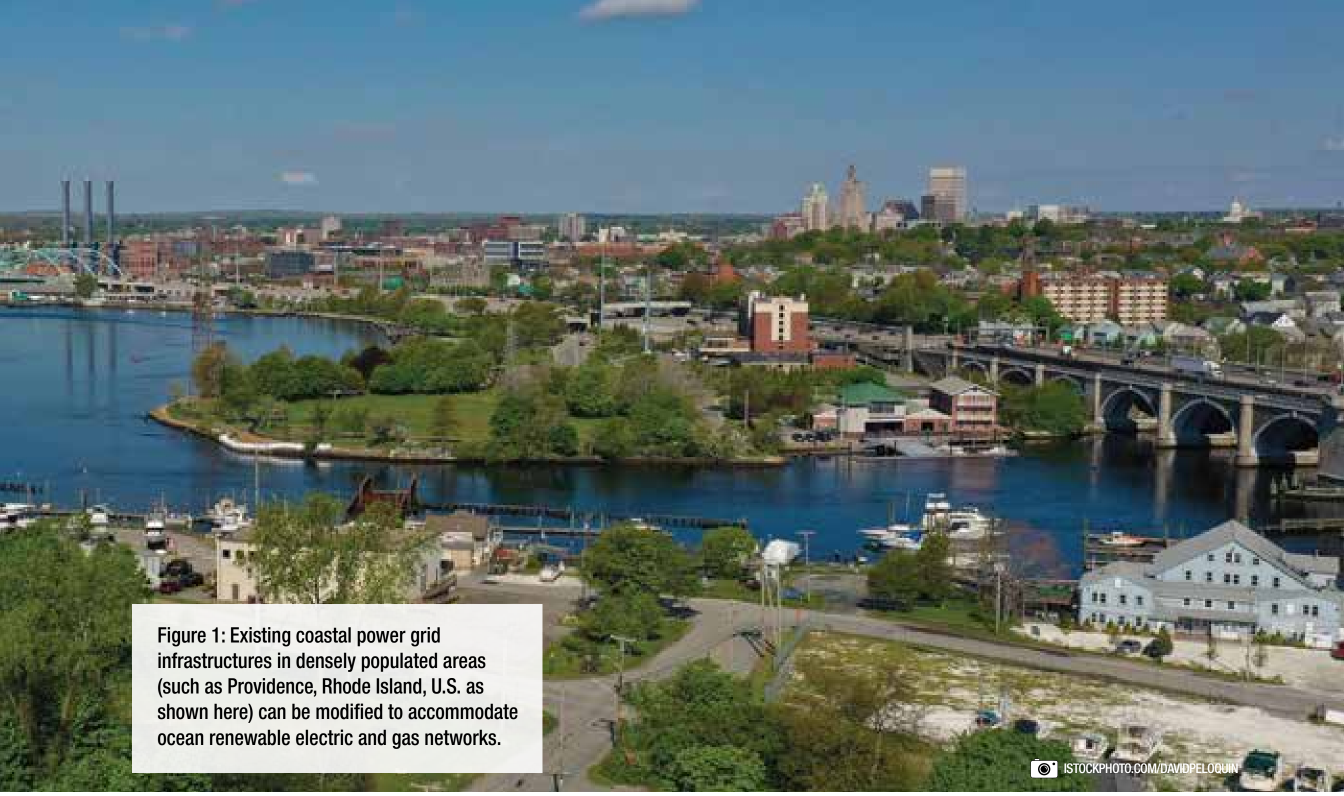

Figure 1: Existing coastal power grid infrastructures in densely populated areas (such as Providence, Rhode Island, U.S. as shown here) can be modified to accommodate ocean renewable electric and gas networks.

sufficient quantities of marine renewable energy devices that remotely help defend coastal infrastructures from rising seas. These factors accompany first location decisions for launching nearshore devices, such as WECs, and subsequent build-out phases for deploying technology farther to sea.

Marine Hydrokinetics

Our symptomatic response to rising seas has been to raise or raze shore-side infrastructure, back up, or enforce with new coastal defenses. Several ports have installed seawall wind turbines and the next apparent stage is oscillating water column (OWC) breakwaters that convert wave batter. As with land and shore-sited wind parks, the need for energy competes with life quality. United States Senator Edward Kennedy (deceased) was among the first public figures to question environmental and visual presence of serially embedded offshore structures. Public opinion is varied regarding views of vertical elements such as cooling and puffing stacks, transmission towers, turbine blades, and sailboat masts. There are some measurable impacts to avian, mammalian, pelagic, and bentho-pelagic species from MHK blade sweep, wake effect, underwater tower vibration, noise, draped cable electromagnetic fields (EMF), scouring and ablation, sedimentation, and seafloor foundations.

Rhode Island is first U.S. state to deploy offshore wind turbines (Figure 2). Its Special Area Management Plan supports marine spatial planning that influences models for other regions. Environmental impact assessments, life distribution analyses, and most developers' innate concern leads industry from fixed offshore wind to deeper floating platforms.

As MHKs nudge from shore, they could possibly be located near wind structures to absorb wave energy dense loads to generate electricity and calmer lee. Global principles apply farther to sea at less convenient, but naturally least offensive, opportunity zones such that management of these sites bridges marine renewable energy industrialization with least technological perturbation. Short-term test disruption can lead to enduring habitat enhancement. The logistical and cumulative impacts of newly stationed machinery intrinsically change ecosystems.

Figure 2: Block Island Wind Farm off Rhode Island is the first commercial offshore wind farm in the U.S. It is located about 6 km from land in the Atlantic Ocean; it was launched in 2016.

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Structures can be biocompatible, reefing attractants, or fouling pathways. In turn, reefing can benefit marine hydrokinetic device operation. Mostly submerged modular frameworks are used as reefs by marine life. Functional symbiosis of bio-conformal stabilizer materials and coatings straddles biogrowth, bio-slip flow moving parts, and clogged system failure.

WEC structures may achieve sea anchorage using horizontal lattice plates fused with 3D bio-printed polymer hydrogels. Such growth platforms of algae and cellulose nanocrystals could accelerate algae repair that restores dying coral reefs. Calmer lee-shaded waters attract and re-invigorate a web of life. Series-connected WEC lattices can possibly grow descending maricultural strings and such systems might also deter invasive species.

WEC operational sensing networks are geospatially "fixed swarm" (Self-organizing Wide area Autonomous vehicle Real-time Marshalling) wave and bio-trackers that provide continuous spatial assessment from pre-deployment baseline. Autonomous and manned surface, underwater, and swarm vehicles and gliders are used for peaceful observation, WEC maintenance, and possibly WEC station keeping.

UV light based detectors and antifoulants should be shielded or avoided. Bio-physical monitoring with sonar, optical, and other emitting means should also be avoided. All EMF generating and distribution equipment must be in shielded containment. Passive visual/acoustical receptors, triggered sampling, and continuous re-evaluation determine MHKs distance from reefs, habitats, migration routes – particularly cetacean – and dead zones.

Marine Protected Areas

The United Nations global High Seas Treaty for "the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction" – the global commons (international waters beyond 200 miles) – prioritizes areas identified for spatial protection, known as marine protected areas (MPA). Signalling MHK devices can be both a guiding aid to navigation and physical barrier from body collisions. Serially connected WEC devices preferably form physical exclusion zones, like fences, outside MPA margins. The premise is that co-sustainable fishing and food production benefits accrue with physical separation of international commerce shipping lanes from MPAs.

MSP using Google Earth

Several wave energy converter modules joined together form arrays of varying size and edge shapes. Transposed on Google Earth (GE) and shown in Figure 3, the 7,053 km black triangle side is divided to thirty 235 km blue triangle sectors. Blue line sea lanes are 19 km wide. Single and double row grid erasure produces 235 km or 470 km wide major sea lanes. Resulting wave energy converter field triangle sides are approximately 216 km. The 50 global blue dots (six dots in Figure 3) provide the buoys' wave data links to the module's power calculator. Improvements would display real-time module array's total energy output and enable global systems supervision and control.

GE facilitates MSP by displaying substantial detail of several factors, environments, and routes; and could accurately show more ecosystem process data. GE's standard platform economically coalesces common inputs to link high density geographic information system spatial datasets. Mariners and scientists, for example, can provide updates of marine species migration patterns. GE static wave height and period maps need conversion to 10-day animated GIF movies that underlay marine renewable energy grids while the installed WEC devices provide data. The GE platform could enable precise remote control of actual WEC deployments, operations and maintenance, performance, and emergency response. The GE twin bridges MSP and real world data to forecast dynamic supervisory control decisions. Mapping thousands of plants, towers, and power lines

OWEB (2,402 triangle sectors)		1% Humanity Locations
1 SE Atlantic	74	4
2 Mediterranean	5	16
3 N Atlantic	82	5
4 SW Atlantic	109	3
5 S Atlantic	194	
6 Indian	255	
7 Arabian Bengal	98	39
8 Arabian	4	13
9 Arctic	9	2
10 NW Atlantic	37	3
11 NE Pacific	183	5
12 SE Pacific	186	3
13 S Pacific	207	
14 W Antarctic	17	
15 E Antarctic-Sern Ocean	43	
16 Tasman	119	
17A Banda	47	
17B Marianas	63	
18 NW Pacific	202	
19 Pacific	257	
20 SW Pacific	211	

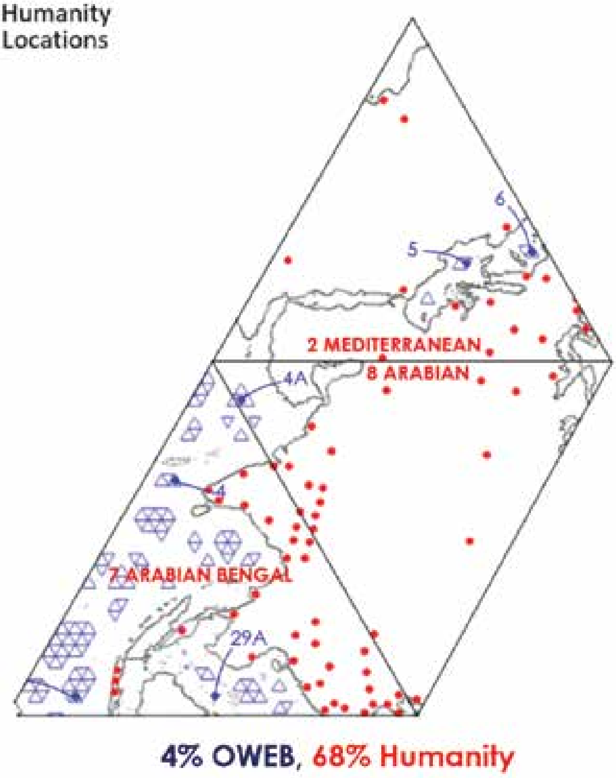

Figure 3: Ocean Wave Energy weB (OWEB) Stage 3 distribution comparison to population density. OWECO

shows almost 65% of intercontinental and island infrastructure in place for a single global renewable energy grid.

Conclusion

As the storage, transportation, and renewable energy transition is underway, marine spatial planning is an essential tool to address the rapidly changing ocean challenges through careful, progressive adaptation. MSP will be a key factor in environmental characterization of potential marine renewable energy sites and will play a significant role in decisions regarding where and how these facilities are ultimately installed. Proper utilization of MSP tools and techniques can help develop a long-term symbiotic relationship between humanity, the marine environment, and marine renewable energy.

Foerd Ames invented OWEC® Ocean Wave Energy Converter and the first wave-driven linear generator in 1978, and founded OWECO Ocean Wave Energy Company. He constructed modules that generated electricity from waves in 1982. Holder of several patents and trademarks, since 1980, his research group constructed novel generator topologies and developed computational performance descriptions. OWEC® technology received the first U.S.A. federal and state wave energy contracts, the National Award for Energy Innovation, and is the subject of publications and demonstrations. Mr. Ames travels globally to establish international standards regarding marine renewable energy. He was technical reviewer to international governmental and private entities including the U.S. Technical Advisory Group, International Electrotechnical Committee TC 114; Intergovernmental Panel on Climate Change; California Energy Commission; and Gerson Lehrman Group Council of Advisors. OWECO maintains the longest continually active wave energy web site since 1994. Mr. Ames received dual degrees from Rhode Island School of Design, U.S.A. in 1980. www.owec.com