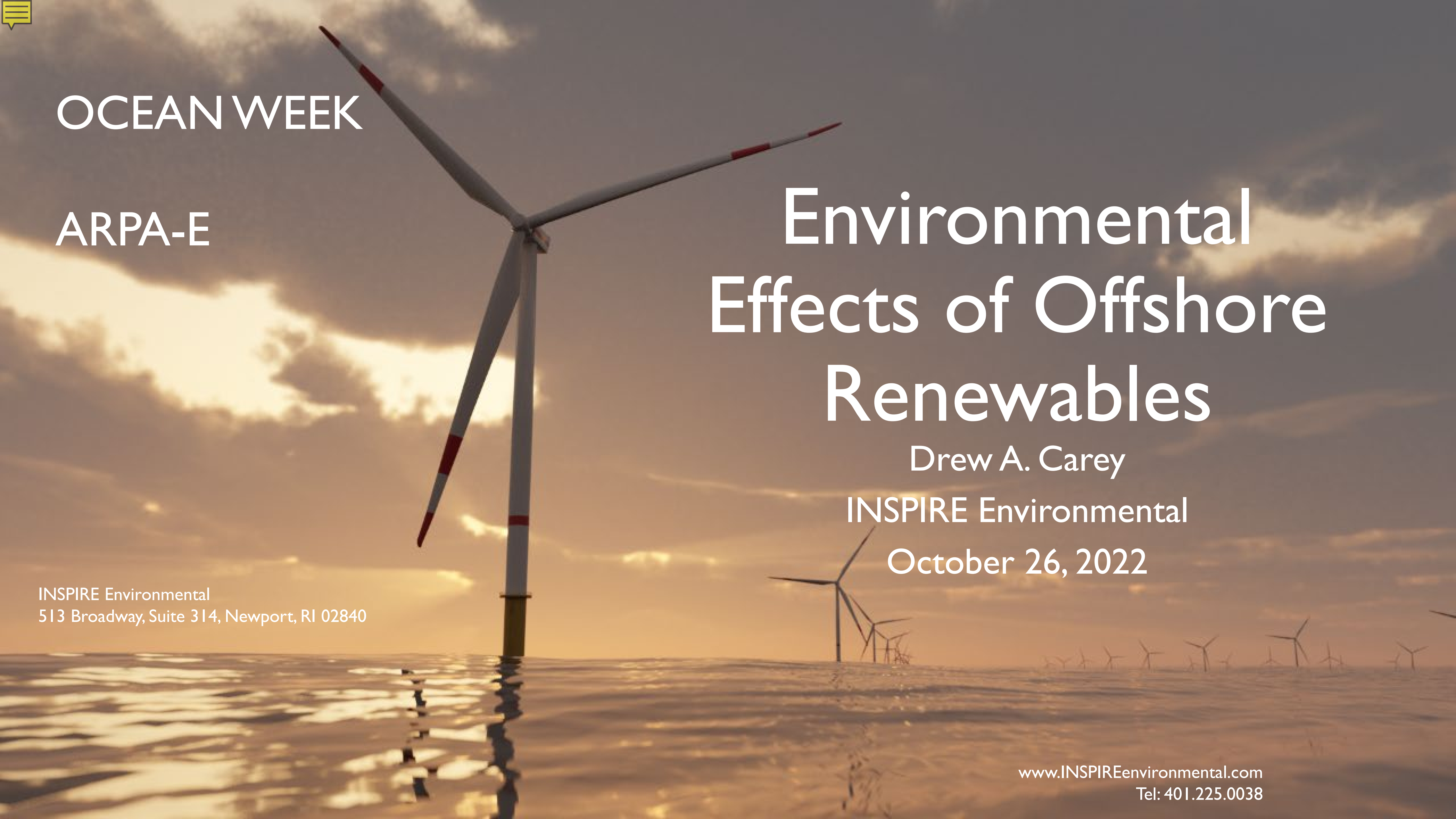

OCEAN WEEK

ARPA-E

Environmental Effects of Offshore Renewables

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October 26, 2022

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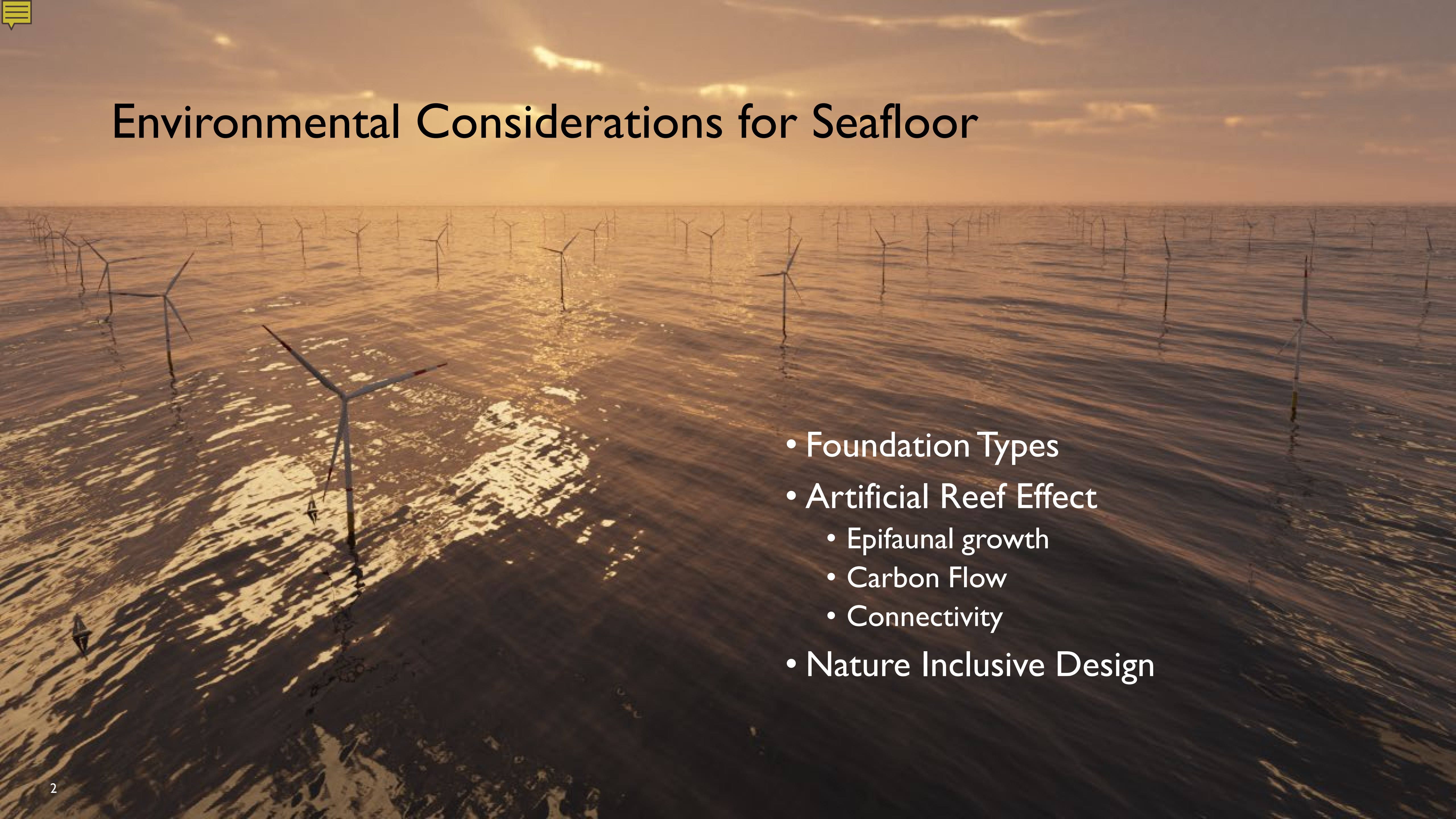
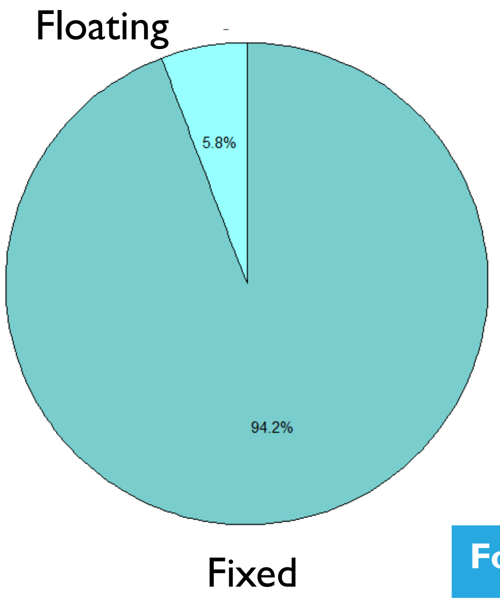
Environmental Considerations for Seafloor



- Foundation Types
- Artificial Reef Effect
  - Epifaunal growth
  - Carbon Flow
  - Connectivity
- Nature Inclusive Design

Foundation Types

Monopile
Lattice Jacket
Gravity Base
Suction Bucket



Foundation Type	MW Capacity
Monopile	30,000
Lattice Jacket	4,700
Gravity Base	735
Suction Bucket	103

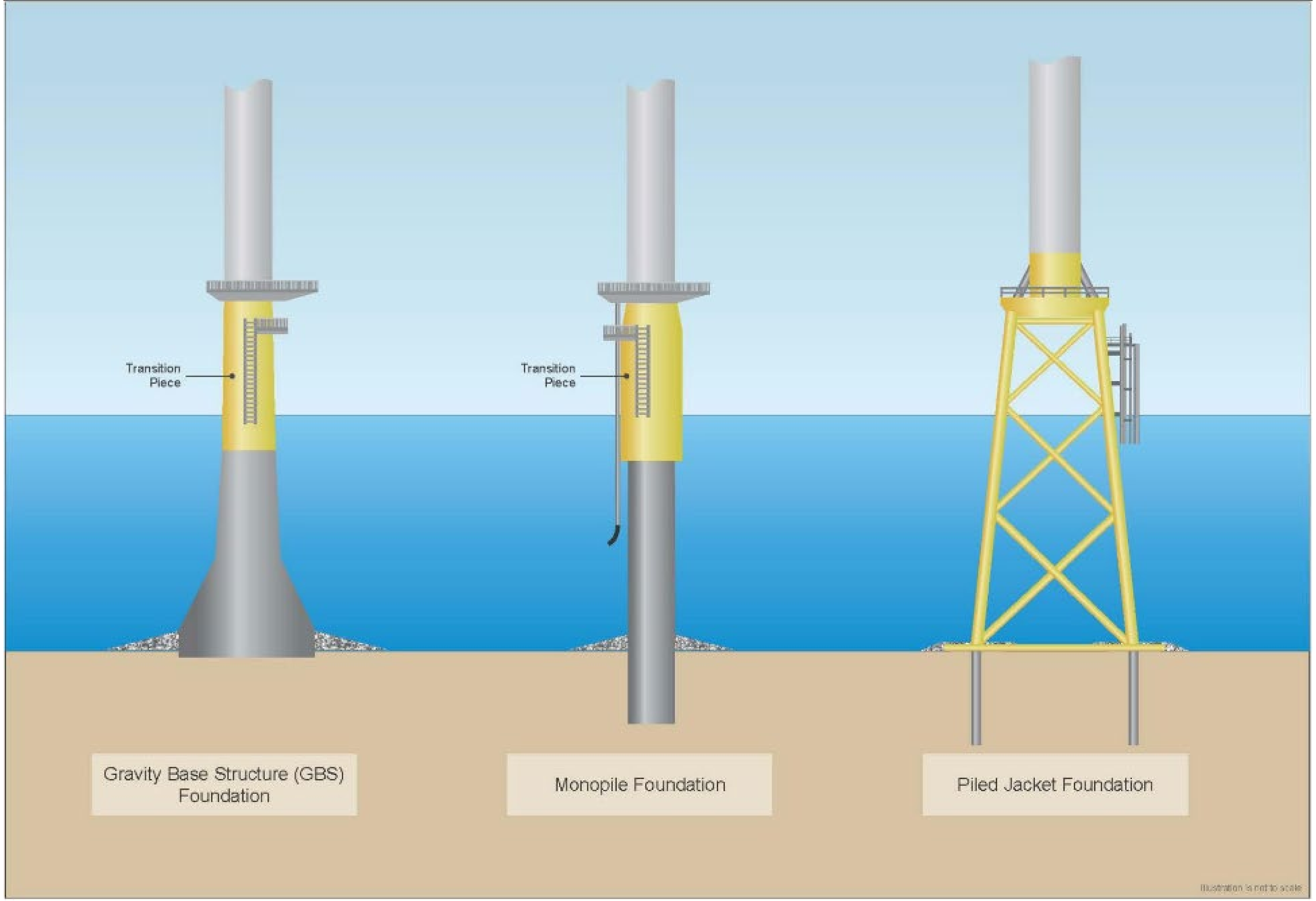
Fixed foundations account for over 90% of all projects to date.

Monopiles dominate with 84% of installed capacity. Jackets were second (13%) with the installation of at 22 projects. Gravity and Suction Bucket are less than 3%

Floating is increasing but has > 50 types

Expect competitive designs for > 40 m (130')

This includes all projects installed globally by October 2022.
Foundation type for those projects with identification of type



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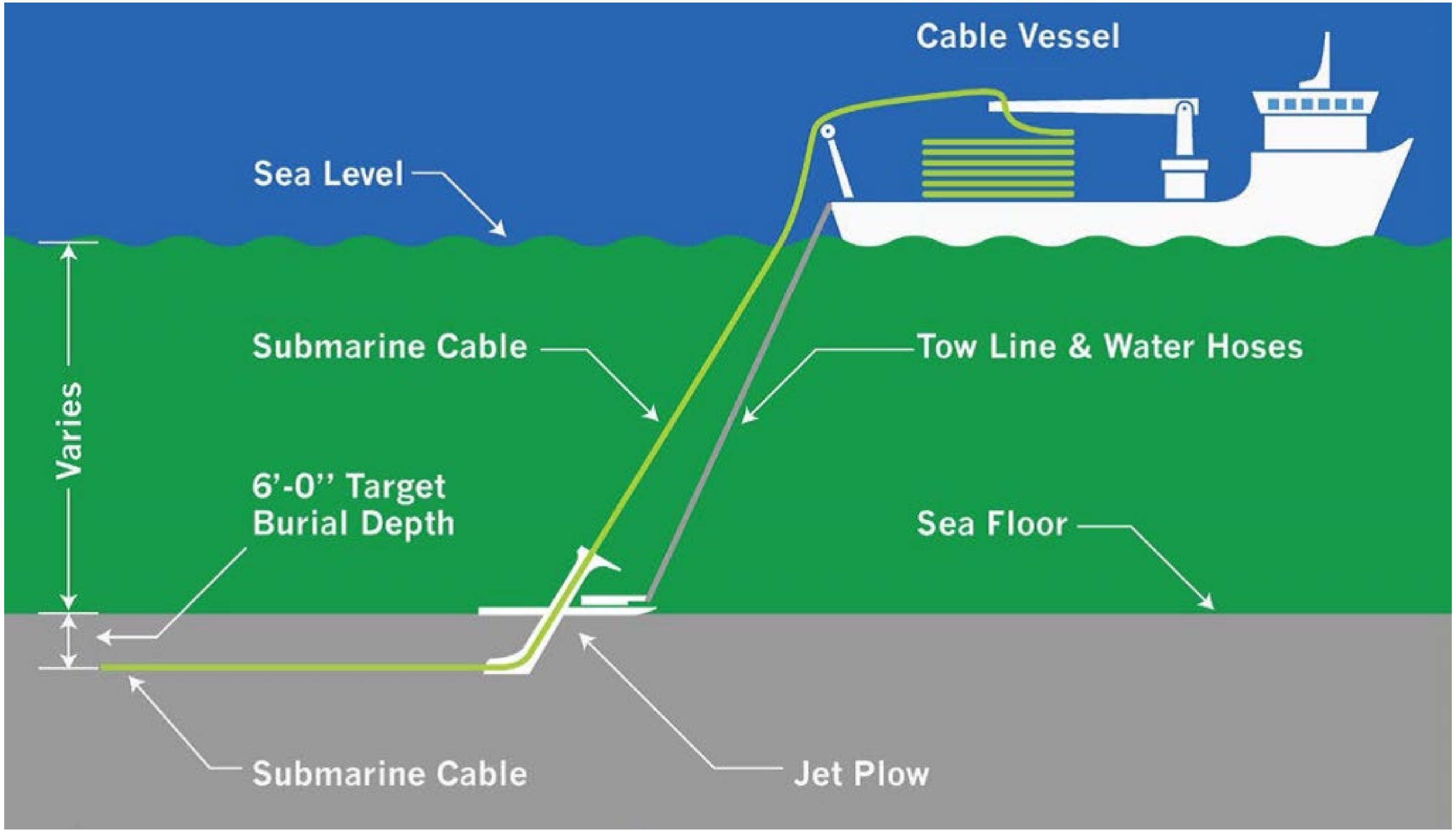
Type	Depth (to date)	Geotechnical Conditions	Acoustic Impacts	Supply Chain	Logistics
Monopile	0.5 - 50 m 1.6 - 164 ft	Low to high load bearing soil Small footprint Surface and subsurface clear of boulders Scour protection	Pile driving Vessel noise	Steel, fabrication Feeder vessels/barge Heavy lift vessel Pile driving	Specialized fabrication and heavy transport Laydown Fast pile driving
Lattice Jacket	20 - 80 m 65 - 260 ft	Low to high load bearing soil Large footprint Surface and subsurface clear of boulders Only filter layer in most cases	Pin pile driving 2.5 x longer Vessel noise	Steel, fabrication Feeder barge Tugs Lift vessel Pile driving	Specialized fabrication and heavy transport Laydown Slower pile driving (x4)
Gravity Base	0.5 - 65 m 1.6 - 213 ft	High load bearing soils (sandy or rocky) Large footprint Flat surface Consistent shallow subsurface Large scour protection	Vessel noise	Concrete, fabrication Lower cost Float to Fixed Bollard tugs Large areas to fabricate and marshall	Less specialized fabrication, highly specialized loadout and marshalling Laydown + Transport + Fast placement
Suction Bucket	25 - 30 m 82 – 98 ft	High load bearing soils Large footprint Shallow subsurface clear of boulders Large scour protection New designs no scour protection	Vessel noise Pump noise	Steel, fabrication Feeder barge Tugs Lift vessel Suction pump	Specialized fabrication and heavy transport Laydown Fast placement

Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations (boem.gov)

Potential changes in benthic habitat from epifaunal growth on surface of base and spread of debris onto scour protection and surrounding seafloor; attraction of structure loving finfish.


Suction Bucket

Cable burial and protection



Typical jet plow

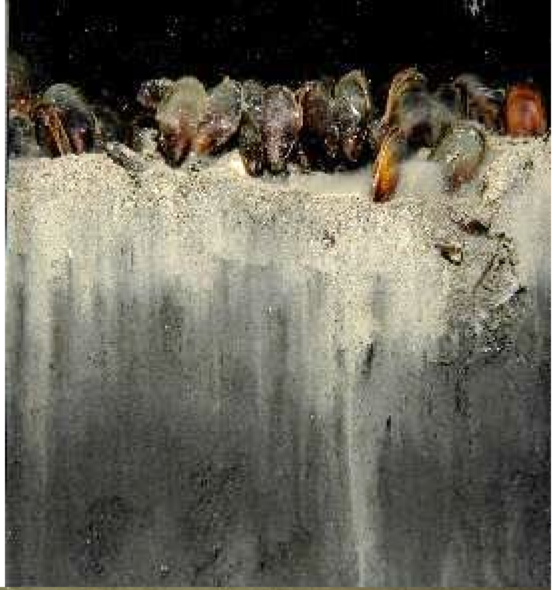
Cable mattress

Artificial Reefs

- All foundation types introduce hard substrata (surfaces) into the ocean
- Intertidal surfaces are not typically found offshore, so vertical ‘island’ from sea surface to seafloor
- Materials used and complexity of structure affects ‘epifaunal growth’ – plants and animals that attach
- Attached epiflora use nutrients and create ‘biomass’ (primary productivity)
- Attached epifauna feed on phyto- and zooplankton in water column, create biomass and discharge waste
- Presence of epifloral and epifauna attract fish and mobile epifauna (crabs, lobsters, small crustacea)
- Presence of structure attracts finfish that use structure as refuge
- Complexity of structure might provide more refuge and variety of use
- Growth and feeding activities increase local biomass (secondary productivity) that spreads to seafloor

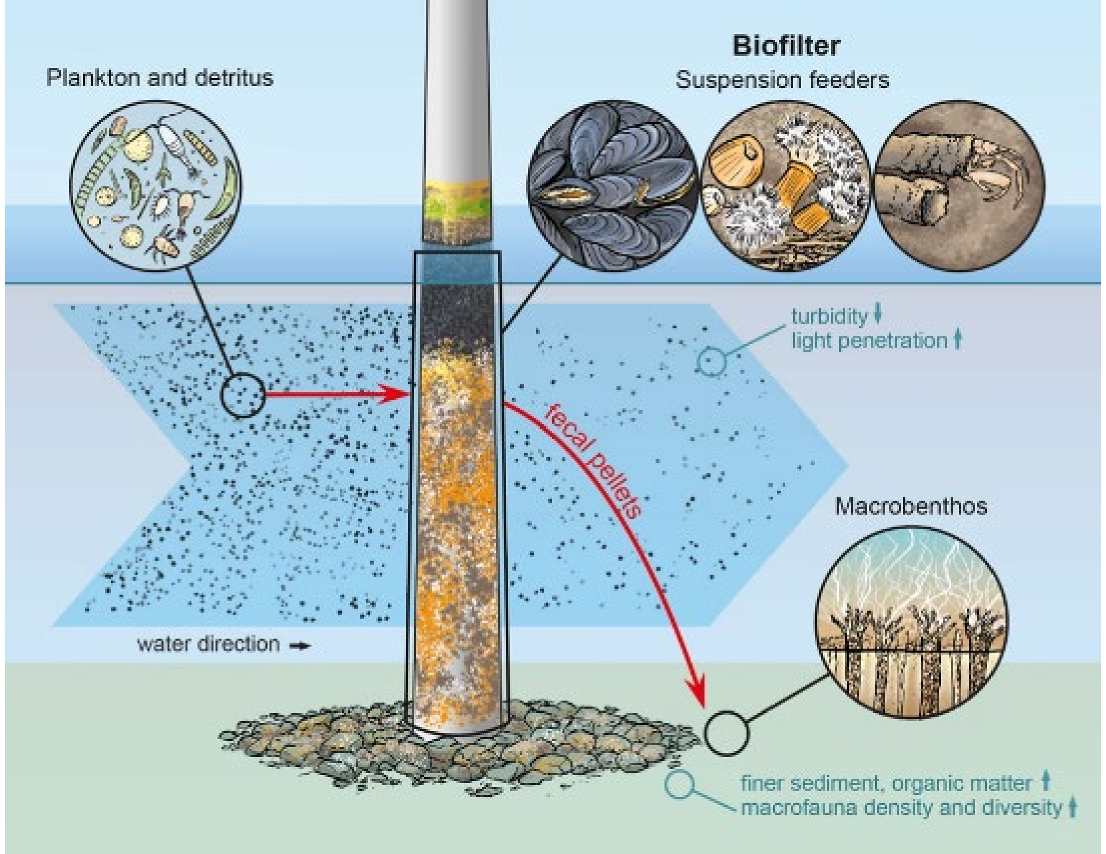
Habitat Changes

- Benthic Habitat Modification
  - Soft sediments
  - Hard sediments
- Enrichment: Benthic-Pelagic Coupling
  - Energy flow
  - Fate of energy
  - Food webs
- Connectivity / Habitat Expansion
  - Islands of complexity
- Habitat Suitability
  - Changing trophic structure

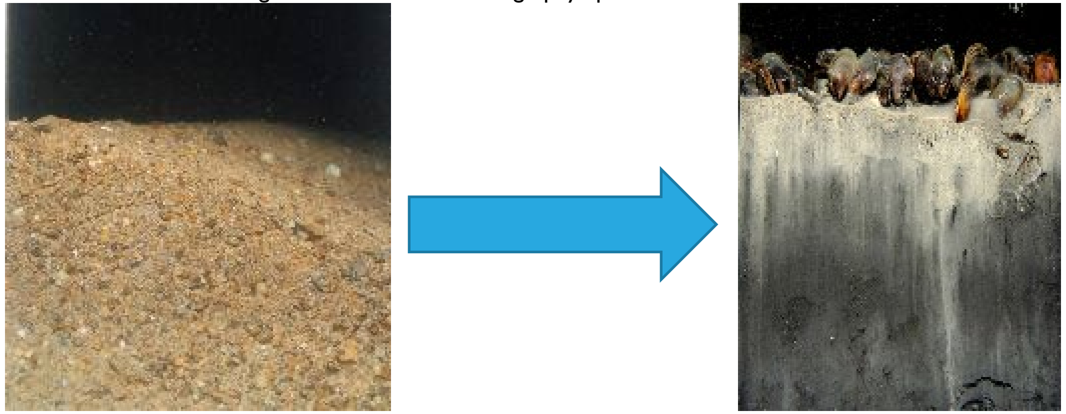


Bottom Sediment Modification

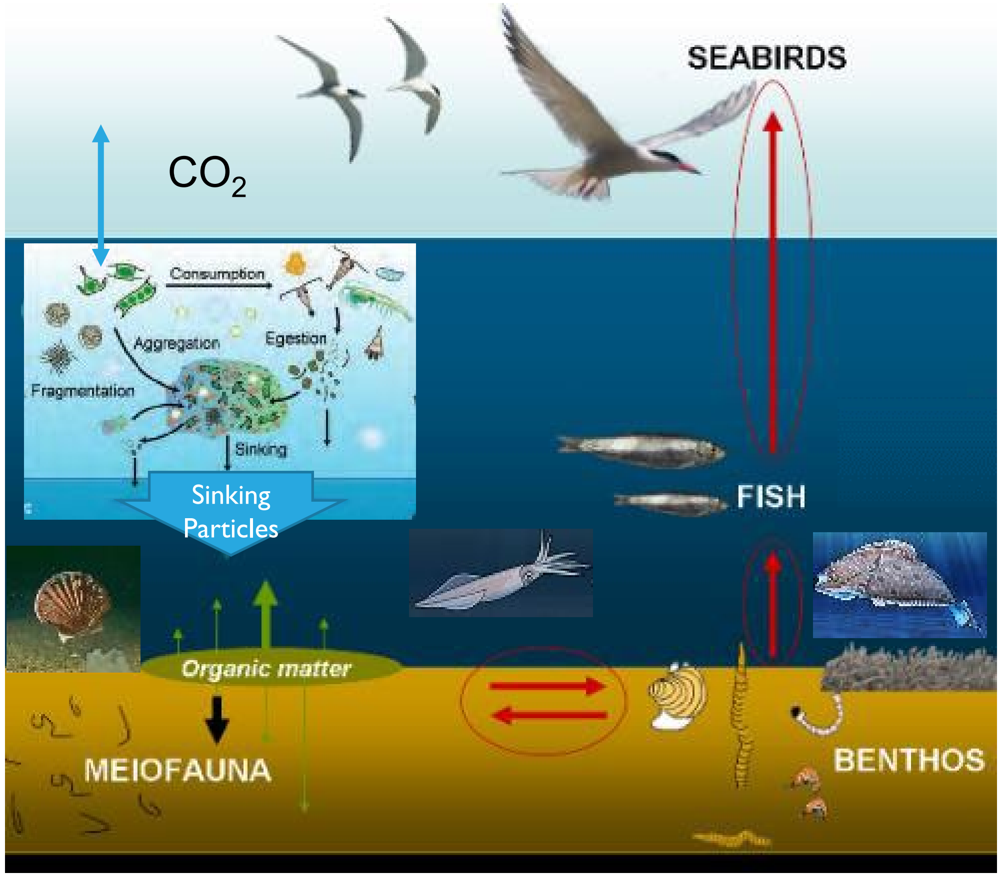
- Organic enrichment
- Energy flow
- What we know
  - Changes in particle size
  - Changes in organic content
  - Changes to flora and fauna
- What we need to know
  - What is the fate of the energy?
  - What is the appropriate spatial scale?



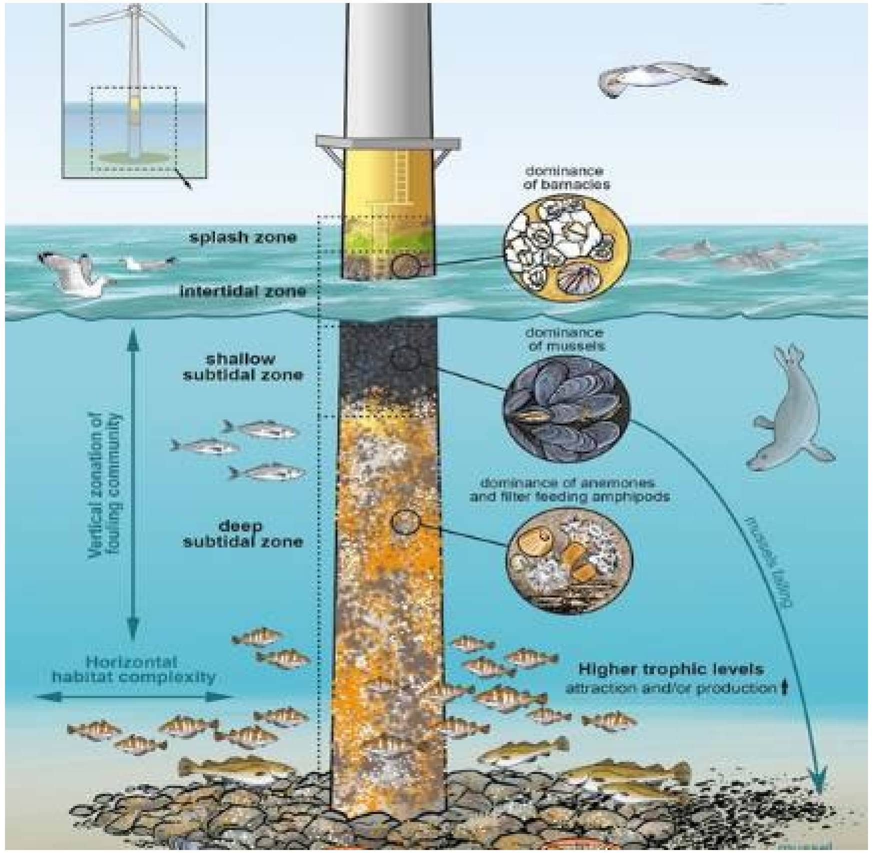
Degraer et al., 2020, Oceanography Special Issue Vol. 33, 4



Benthic-Pelagic Processes in shallow shelf (0-100m) before and after WTGs



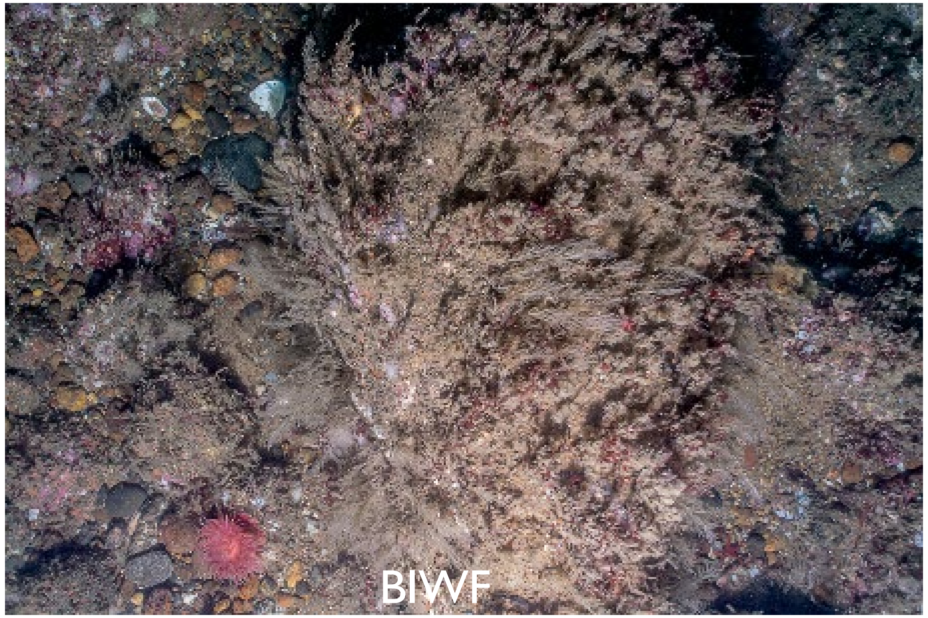
From WestBanks vliz.be, Buessler et al., 2007, Pew Trust



Degraer et al., 2020, Oceanography Special Issue Vol. 33, 4

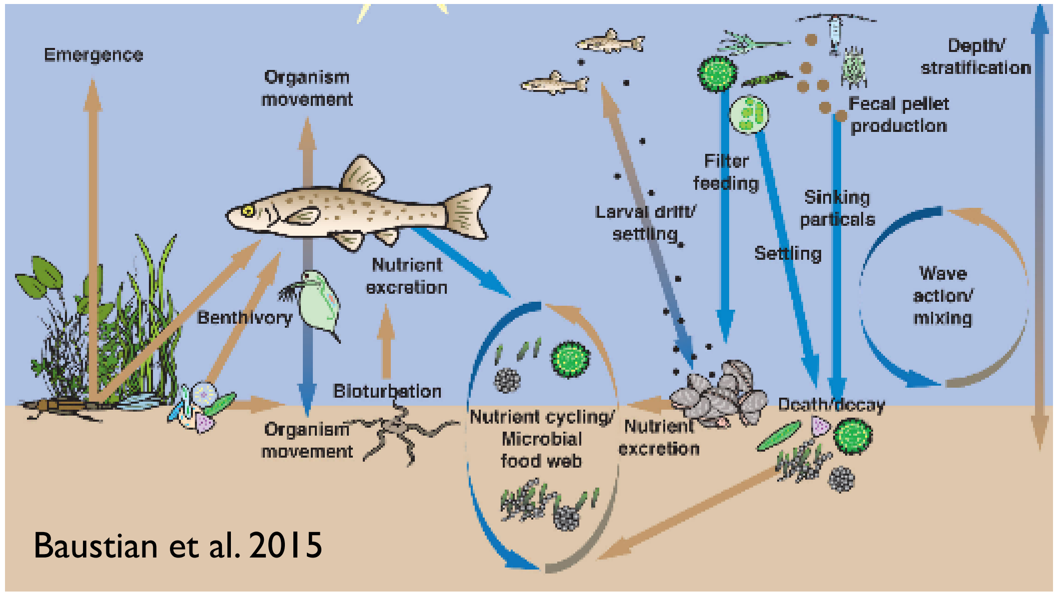
Energy flow to Benthos

- Primary production captured locally (energy in phytoplankton or epiflora)
- Energy turned into biomass of epifauna (gC or kJ)
- Energy exported to benthos (soft and hard)
- Energy exported to demersal-pelagic fish and invertebrates
- Increased secondary production in benthos and water column
- Alter food web to support scavengers, surface deposit feeders



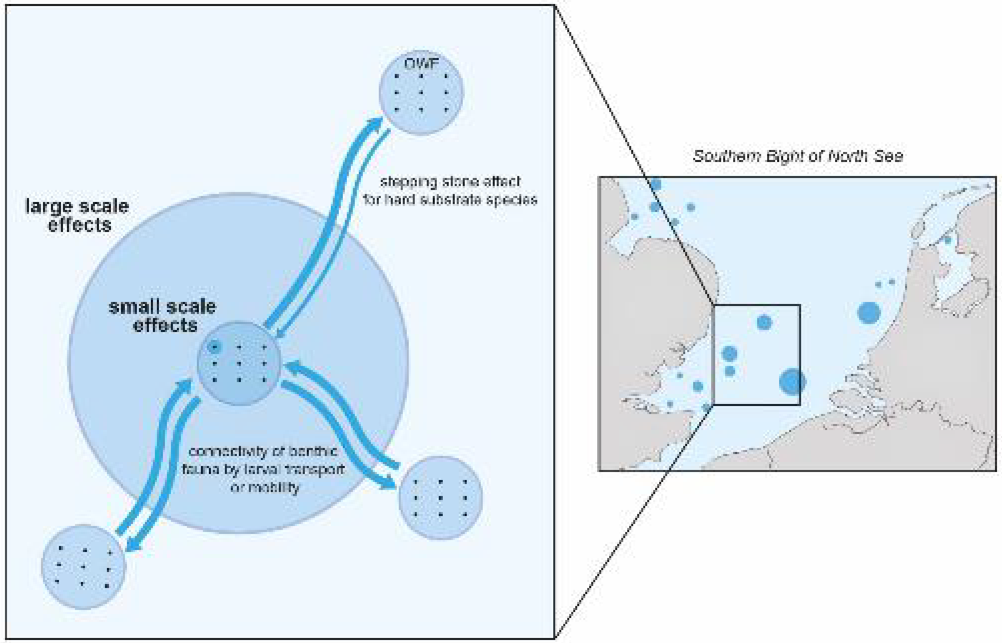
Biomass exported to other habitats

- Mobile predators move away from site – energy export
- Mobile predators stay at site – energy to benthos
- Suspension feeders feed on waste – energy to benthos
- Detritus and shell litter – energy to benthos (some refractory)
- Remineralization of detritus in benthos
- Release of energy back to water column



Connectivity

- Introduction of inter-tidal habitat in deeper water
- Potential habitat expansion for both desirable and undesirable species.
- May be affected by the nature of benthic habitats near projects (Wilhelmsson and Malm, 2008)
- What we know
  - Inter-tidal species colonize offshore structures
- What we need to know
  - At what scale does this connectivity move from small-scale effect to large scale effect?



Degraer et al., 2020, Oceanography Special Issue Vol. 33, 4

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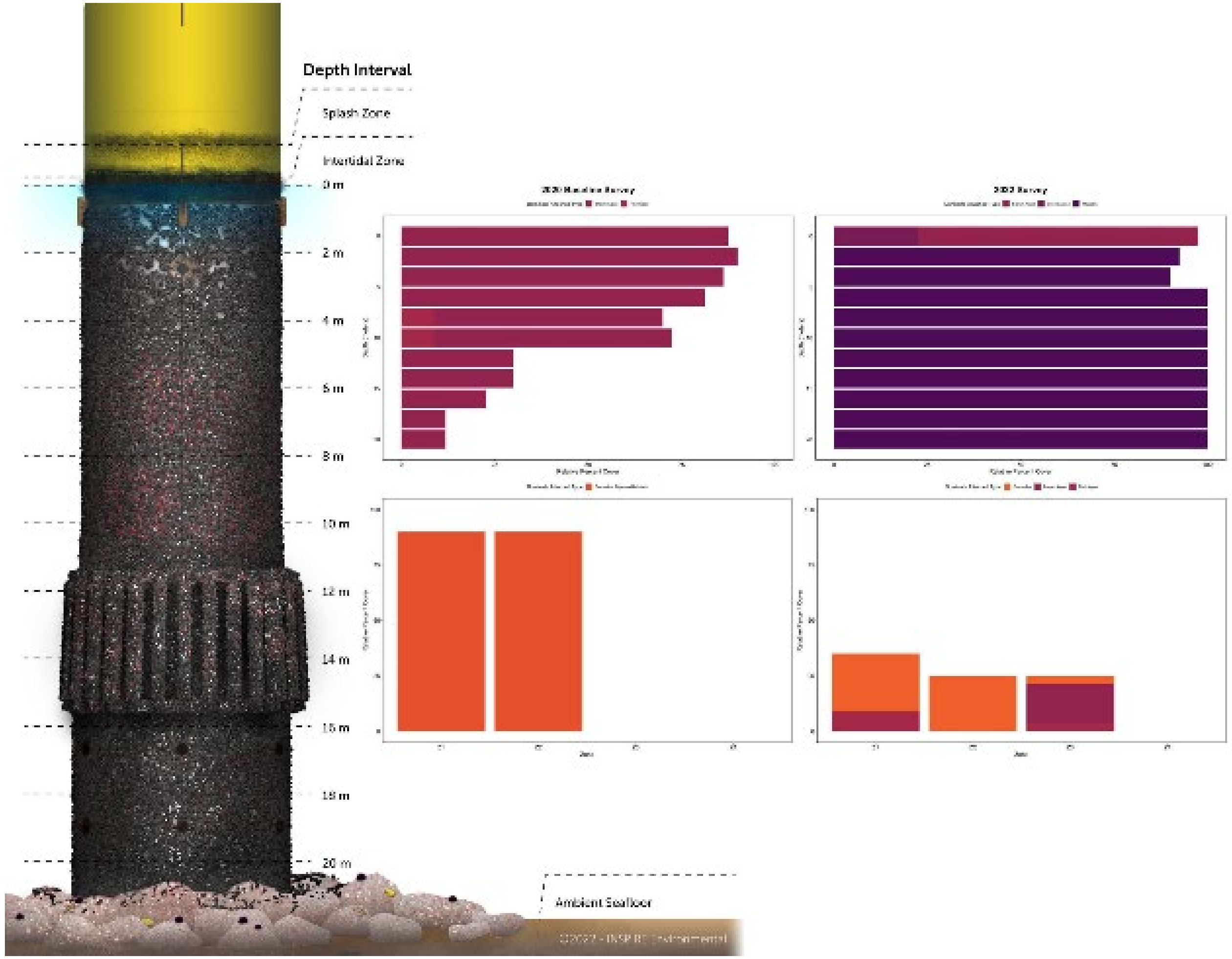
Habitat Suitability

- Food web dynamics
  - Primary productivity
  - Predator-prey relationships
- What we know
  - Documentation of species presence/absence
  - Spatial/temporal resolution
- What we need to know
  - How does this affect habitat function?
  - How is it functioning at an ecosystem scale?
  - Is effect positive or negative? Functionally equivalent?



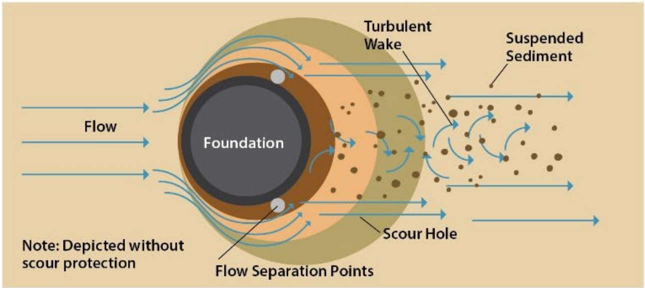
CVOW after 2 years

Wake and scour effects

- Turbulence created by structure = wake effect
  - May affect suspended sediment, larval dispersal, refuge
  - Likely a few 100 m in tidal currents
- Wake effects on seafloor can cause differential scour
  - Greater with shallower water
  - Greater with larger diameter
  - Can alter benthic habitats

- Similar across foundation types
- Less wake effects from lattice jacket
- More scour from gravity and suction bucket monopiles

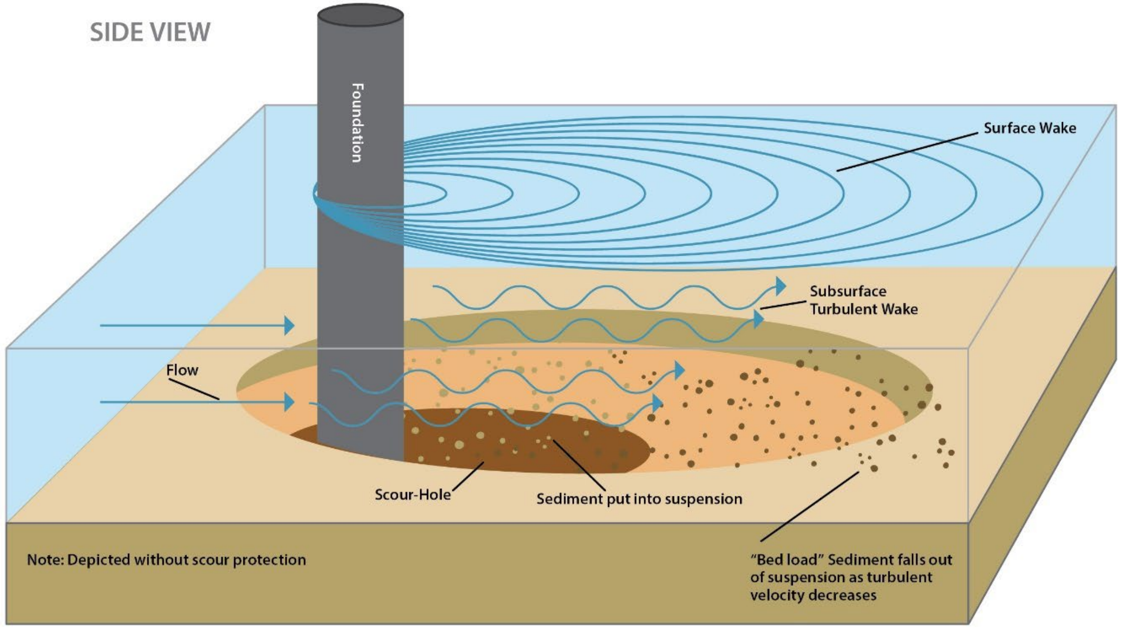
TOP VIEW



BOEM 2021-053

TURBULENT WAKE EFFECT
ON SEDIMENTARY PROCESSES
(SCOUR, EROSION, AND SUSPENSION
AND TRANSPORT OF SEDIMENT)

SIDE VIEW



Nature Based Design

Designing Offshore Wind to Work With Nature

Nature Based Design includes options that can be integrated in or added to the design of offshore wind infrastructure to create suitable habitat for native species or communities whose natural habitat has been modified, degraded, or reduced.

Enhanced Scour Protection Layers

A combination of large and small structures with various sized holes, and/or rocks with a range of shapes and sizes increases the surface area and habitat complexity of scour protection layers. This promotes biodiversity by providing adequate shelter for large, mobile species, and suitable refuge for smaller species, juvenile life stages, and epifaunal organisms.

Mimicking Natural Hard Bottom Habitat

Benthic habitat conditions for native species can be optimized by mimicking natural hard bottom habitat features of the region.

Materials Designed to Promote Growth

Calcium carbonate (CaCO3) or natural shell can be mixed into concrete structures to provide suitable chemical composition for larval settlement of calcareous organisms such as bivalves.

INSPIRE ENVIRONMENTAL & The Nature Conservancy

QUESTIONS?

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