Algal Ecology

Ecology: Living in a marine environment

Patterns, Processes, and Mechanisms

Some factors affecting Algal Ecology

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All act together in nature!
I. LIGHT

= Amount of radiant energy impinging on a unit of surface area

Measurement:

Irradiance measured as: amount of energy falling on a flat surface

Measured as a rate:

- Microeinstins (= Micromole photons) per square meter per second
- Watts per square meter

Algal point of view: light is extremely variable in space and time:

- Predictable variation:
  - Latitude
  - Seasonal changes in day length

- Less predictable variation:
  - At the surface = waves, white-caps, foam
  - In the water = turbidity from silt, particulate matter, phytoplankton blooms
PAR = Photosynthetically Active Radiation (400nm - 700nm)

**Attenuation of Light with Increasing Depth**

*Attenuate: to lessen in severity, intensity, or amount*

At ~ 100 m even in clearest water, only 1% of surface radiance makes it through

**Different wavelengths** transmitted to different depths

Energy inversely related to wavelength

Violet = short wavelength/high energy (blue or green goes farther)

Red = long wavelength/low energy (red drops out first)
Light attenuation is due to:

- **Absorption** (long wave length, low-energy wavelengths absorbed first, by water itself.)

- **Scattering** (high energy, short wave lengths scatter due to water molecules and particulates)

Effect of Salinity?
Effect of Turbidity?

Clear oceanic water (I-III)
- Max transmittance in clear water occurs at ~475nm
- Blue/Green region
- 98% of surface

Coastal/estuarine water (1-9)
- Max transmittance in opaque water occurs at ~575nm
- Yellow/Orange region
- 56% of surface
How do algae cope with attenuation?

1) Pigments

Across species:

- Different Divisions have different pigments, allow potentially different depth distributions

Engelmanns Theory of Chromatic Adaptation (1884)

Appealing, but wrong (Saffo 1987)

Irradiance not spectral quality

1) produce more accessory pigments
2) produce more photosynthetic pigments
3) morphology matters- thicker fronds, arrangement of chloroplasts
Ecological Reality:
red, green, and brown algae mixed throughout intertidal and subtidal zonation complexity – abiotic and biotic forcings

How do algae cope with attenuation?
(1) Pigments

Within species

✔ Change ratio of accessory pigments

✔ Up-regulation of pigments
  (make more of everything)

✔ Change size of PSUs
  antennae + reaction center
  (bigger is more efficient at low light levels)
Model for comparison of Ps/I curves within species: photoacclimation

From Ramus 1981

How do algae cope with attenuation?

(2) Morphology

Surface area: More surface to capture light, crustose algae should do best in dim habitats, less self shading
Thallus thickness: Thicker thalli should have a growth disadvantage in dim habitats, also self-shading
Comparison of Ps/I curves across species: photoadaptation

- Affects all levels of biological organization - molecules, cells, organisms, communities. In algae - photosynthesis, enzymatic activity

**Too high?** - Denatures proteins, damage enzymes, membranes

**Too low?** - Low enzymatic activity, disrupts lipids, membranes, ice crystal formation

**Lethal temp set by tolerance of most susceptible life history stage**
All algae are single celled at some stage of life history, even the big kelps: a species’ distribution is determined by effect of biotic and abiotic factors across all stages of its life history.

Isotherms

- Boundaries defined by the same surface water temperature averaged over many years for a particular month
- Northern and southern limit dictated by February and August Isotherms
Seaweed Floristic Regions
1. Arctic - depauperate

2. Northern Hemisphere Cold Temperate - Laminariales
   - Atlantic & Pacific have distinct communities

3. Northern Hemisphere Warm Temperate

4. Tropical
   - 180 million years, 20 °C isotherm

5. Southern Hemisphere Warm Temperate

6. Southern Hemisphere Cold Temperate - Durvillaeales
   - similar around the southern hemisphere

7. Antarctic - 1/3 of 100 species endemic

Best correlate for algal biogeographic patterns:

Temperature

Other correlates:

✓ Day length
✓ Latitude
✓ Currents

Confounded w/ temp

So why temperature?

- Experimental evidence w/single spp
- Northern cold temperate southern limits set by summer high
- Warm temperate/tropical spp northern limits set by winter low
- Thermal boundaries shift with global warming/cooling events
Potential problems with invasive species?
- Increase in dispersal rates, changes in dispersal patterns
- Global warming and shifting boundaries

- *Codium fragile* is a pest in Japan
- *Colpomenia from Japan* is a serious problem in European oyster beds
- *Caulerpa spp.* has become a pest in the Mediterranean (San Diego?)

III. Salinity

**Definition** = Grams of salts per kilogram of solution
**Measurement** = Refractometer: measures light refraction

- Unit of Measure - ppt or °/oo, parts per thousand.
  (1kg seawater contains 34.7 g of salts \(\rightarrow\) 34.7°/oo)

- Range - oceanic 32-38ppt, estuarine 1-32ppt
III. Salinity
Osmoregulation in seaweeds

Seawater is hypotonic (less saline) than most algal cells

• Seaweed cells lack contractile vacuoles to pump water out
• Seaweeds prevent bursting due to water diffusing in by pumping ions both in and out
• Tolerance of hypersaline water (e.g. in tidepools) depends on elasticity of cell wall (prevents plasmolysis = cell wall tearing away from cell membrane due to water rushing out).
• Tolerance of freshwater (even more hypotonic) depends on ion pumping ability and strength/elasticity of cell wall
• Osmotic stress (in either direction) can act synergistically with temperature
• Gametes and spores are especially sensitive

III. Salinity

Euryhaline: Species that can handle a wide range of salinities

Stenohaline: Species that can only survive in a narrow range of salinities

High Salinity:
- Tidepools

Low Salinity:
- Estuaries
- FW seeps
III. Salinity
The Baltic Sea: a huge estuary = brackish water

- Marine seaweeds (e.g. *Fucus*) occur there but are smaller morphologically (smaller thalli or smaller cells) and have different abiotic optima
- Local adaptation

IV. Nutrients

*Macro-nutrients necessary for algal growth = C, H, O, K, N, S, Ca, F, Mg, P*

*N is often limiting in coastal waters, needed for amino acids, protein synthesis, nucleic acids*
Seaweeds and Nitrogen:

Ammonium (NH$_4^+$) and nitrate (NO$_3^-$) are the most common and used nitrogen sources; NH$_4^+$ is preferred because it can be utilized directly (energy saving).

NO$_3^-$ assimilation by nitrate reductase requires iron (phytoplankton cannot exhaust high NO$_3^-$ pools in Fe-limited Antarctic oceans; famous Fe-addition experiment), more energetically costly.

Cyanobacteria can fix atmospheric nitrogen = convert N$_2$ to NH$_4^+$; 25-60% of this fixed nitrogen is released into the water.

Variation in nutrient availability in space and time:
Issues of depth stratification, role of upwelling
Variation in nutrient availability in space and time:
Issues of depth stratification, role of upwelling

- Chlorophyll = measure of photosynthesis
- Irradiance higher in shallow water
- Nutrients usually higher in deeper water
- Maximum Ps happens in the middle.

Processes that make nutrients available to algae:

- Upwelling
- Nitrogen fixation by Cyanobacteria
- Bacterial decomposition
- Runoff in coastal areas
- Defecation by animals
- All macroalgae have a boundary layer of water around the thallus, affects contact with nutrients, gasses.

- Algae depend on water motion to deliver gasses, nutrients, and remove \( O_2 \) from their surfaces.

- e.g., *Macrocystis*, nitrate uptake increases by 500%, and \( P_s \) by 300% if flow goes from zero to 4 cm/second.

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**Interaction of Water Flow and Morphology**

In relatively still water (e.g., protected coves), surface area becomes really important (more surface area = more diffusion).

*Algae in these environments tend to have high \( SA:V \) = maximize uptake of nutrients*
Costs of high SA:V? In high flow environment = leafy, foliose shapes are a drag 😊

- Variation in species composition on wave exposed vs. wave protected shores = particular morphotypes consistently found in particular flow environments

- Variation within species = phenotypic plasticity in traits that affect water flow around the algal thallus

e.g. Nereocystis “ruffles” and wide blades in protected areas
Complicated effects of water flow

<table>
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<tr>
<th>Positive effects:</th>
<th>Negative effects:</th>
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<tr>
<td>Reduce shading by re-arranging thalli</td>
<td>Damage, destruction</td>
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<tr>
<td>Mixing of nutrients</td>
<td>Loss of settling zygotes/germlings</td>
</tr>
<tr>
<td>Reduce boundary layer</td>
<td>Energetic expense of structure</td>
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<tr>
<td>Dispersal of spores, gametes, zygotes</td>
<td>Inhibits external fertilization in some spp</td>
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VI. Tides

Littoral zone = intertidal zone

Supralittoral = above mean high water, rarely submerged
Sublittoral = below mean low water, permanently submerged
• Sun and moon pull in the same plane at full and new moon (= spring tides, big changes in tide ht), and compete at half moon (= neap tides, smaller change).
Sun and moon have different gravitational strengths (previous slide) and topography of ocean basin modifies tidal current so that high (and low) tides are not same height. This is referred to as mixed semi-diurnal tides.

Tides = Periodic “waves” that result in a change in water level generated by the attraction of the moon and the sun.

- Frequency and amplitude of tides affected by the tilt of the earth and morphology of the ocean basin.
• Diurnal, mixed, and semidiurnal in different locations.

- Frequency and amplitude of tides affected by the tilt of the earth and morphology of the ocean basin.
Tides help to determine zonation patterns in intertidal

*Tides are sinusoidal.* Appearance of the sine wave tidal function might lead one to believe that the relationship between **immersion time** (time underwater) and tidal height decreases smoothly (and linearly or gently curvilinear) with increasing tidal height:

\[
\text{Mean no. hr of immersion (} = \text{ submergence)}
\]

low

high

tidal level (= height in intertidal)

Does this correspond intuitively to sharp breaks in zonation patterns?
Doty (1946, Ecology 27:315-328)

Pattern: sampled distributions of species of macroalgae along CA and Oregon coasts and found (at all sites):

- Six distinct zones
  - crustose coralline reds (cc)
  - Mastocarpus (M)
  - Endocladia (En)
  - Egregia (Eg)
  - fleshy reds (fr)
  - Laminaria - kelp (L)

General hypothesis: tidal fluctuation and differential tolerance to immersion causes zonation of species in intertidal

Specific hypothesis: species zones will correlate with discrete zones of immersion ("critical tide levels")
Doty (1946, Ecology 27:315-328)

**Test:** Calculated the actual immersion times over the tidal range:

Literally cut and weighed tide tables!

**Results:** dramatic non-linear steps in immersion that correlated with algal zonation!

**Conclusion:** physical factors - immersion - control species distribution and determine zonation of species in intertidal

Harsh environment: temp, desiccation, wave stress, salinity, light
Intertidal organisms show striking patterns of zonation

Zonation Patterns
Zonation Patterns - physical factors and biotic interactions
Adaptations to living intertidally:

- Wicked holdfasts for attachment
- Morphology that minimizes drag, shear stress
- Tolerant of high temps (H2O temperature typically 10-17 degrees C along Central Coast; in tide pools, up to 30 degrees C)
- Desiccation tolerance (some algae can survive 60-90% water loss), some require low tide for survival
- Synchrony in gamete release (e.g. intertidal Fucoïds, like Silvetia compressa)
- Photoprotective pigments

VII. Sand Burial

How do algae deal with this?
Two basic strategies: recover or resist

Opportunistic spp: 
*Chaetomorpha, Ectocarpus, Ulva*

Stress "tolerators": 
*Gymnogongrus, Laminaria sinclairii, Neorhodomela*