

Semiosis aspects of
ecosystems of the invasive
Caulerpa taxifolia

BIOSEMIOTICS 2005 

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Contributors

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biophysics.sbg.ac.at/home.htm

What is *Caulerpa taxifolia* ? (1/2)

Taxonomy: *C. taxifolia* is a marine plant grouped into

Division: Chlorophyta

Class: Chlorophyceae

Order: Bryopsidales

Family: Caulerpaceae

Genus: *Caulerpa* (J.V.F. Lamouroux, 1809)

Species: *Caulerpa taxifolia* (Vahl) C.Ag., 1817



Photo NOAA

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- i) The **Chlorophyta** (green algae) groups unicellular or multicellular photosynthetic organisms characterized by the presence of chlorophyll a and b, as well as various carotenoids. The carbohydrate food reserve is starch, which is stored in plastids. There are about 7000 known species.
- ii) The **Ulvophyceae** is one of the 3 classes currently recognized in the chlorophyte lineage, the others being Chlorophyceae and Trebouxiophyceae (formerly Pleurastrorphyceae) and is made up of approximately 1100 species clustered among 100 genera. Most of which are found in temperate and tropical marine environments, and the majority of green "seaweeds", including well-known species of besides *Ulva* and *Acetabularia* besides *Caulerpa*, are placed in this class as well. Conversely, the Chlorophyceae and Trebouxiophyceae, and the Streptophytes, consist almost entirely of non-marine organisms. In classifications based on morphology and ultrastructure, the Ulvophyceae have been separated from other chlorophytes mostly on the basis of characters associated with mitosis, cytokinesis, and the flagellar apparatus of zoospores and gametes. In molecular analyses, however, the relationships among these three classes are less clear. Moreover, the "siphonous" orders of Ulvophyceae (Cladophorales, Dasycladales, Caulerpales) are difficult to resolve vis-à-vis each other and with other Ulvophyceae (orders Ulotrichales and Ulvales); phylogenetic trees based on single gene sequences reveal long branch lengths between "siphonous" sequences and those of other chlorophytes.
- iii) Members of the order **Caulerpales** contain marine (sub-) tropical macrophytes with multinucleate siphonous forms, without cross-walls or segregative division, filled with numerous plastids (e.g. amyloplasts which is an unpigmented plastids for starch storage). Thus forming one huge cell, which is vulnerable to substantial plasma loss. Caulerpales though, are equipped with efficient wound healing properties (upon damage, healing occurs in seconds, involving actin-mediated contraction and a plug of cell wall material). The skeletal constituent of the cell wall contains xylan rather than cellulose and is reinforced with a multiaxial construction, and sometimes even stabilized with calcium carbonate deposits as in *Halimeda* sp. (²⁻⁴Strassburger, 1998). The thallus among members of the genus *Caulerpa* - in which approximately 75 species are currently recognized - is non-septated but siphonous in structure and reinforced with anastomosing strands of wall material (trabeculae) which are ingrowths of the cell wall. A thin layer of cytoplasm, containing countless numbers of each type of organelles, is appressed to the wall (²⁻⁵Silva, 2002). Division of labour is achieved between photosynthetic chloroplasts and starch-storing leucoplasts (heteroplastidy).
- iv) Furthermore, *Caulerpa* possess siphonaxanthin and siphonein as photosynthetically active pigments. This alga exhibits some particular biological and physiological features: resistance to low temperature, gigantism of the thallus, high growth rate, which differentiate it from the tropical strain.

What is *Caulerpa taxifolia* ? (2/2)

Morphology:

C. taxifolia is characterized by

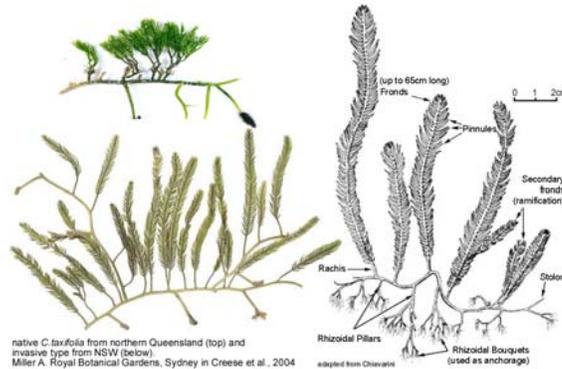
Fronds: feather-like and divided leaves;

Rachis: erect midrib axis

Pinnules: up-curved "feathers";

Stolon: horizontally running shoot;

Rhizoids: rootlike extension used for anchorage & nutrient absorption;



The mutant form is characterized by **GIGANTISM**.

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- i) **Fronds:** One of the more striking external features regard the dimensions of the vertical fronds or pinnae (L. feather, the large but divided leaf). Fronds may be quite short or even absent in shallower water (leaving only the stolons), but are longer in deeper water with prevailing low light conditions. In the tropical version, primary fronds are 2-15cm in length, while those of the Mediterranean strain range reach average frond heights of 25cm - ranging from 5cm in shallower water, to 40cm at depths of 15m, and even to 60-80cm at greater depths. Starting from the base, each frond is made up of the midrib or rachis (Gk. backbone), which represents the prominent central axis.
- ii) **Rachis** (Gk. backbone) is the main axis of the leaf (frond), from which the pinnule arise.
- iii) **Pinnules** (L. small feathers) grow out of this midrib to give each frond the characteristic feather-like appearance. Ramificating or branching fronds originate from primary pinnules. Pinnule length typically measures 1cm while pinnule density per side varies from 4 to 7/cm of rachis length. The shape of the pinules is usually up-curved, tapered at the ends, with some even bifurcated at the top ends (split in two). Pinnule spacing and length is light dependant.
- iv) **Stolon** (L. shoot): Regularly spaced fronds are attached to the horizontally running stolon and is also the origin of the adventitious rootless or rhizoids. After the winter break stolon regrowth of the aquarium strain originates from old stolons that have survived - maximum stolon length is 2.8m, while the overall cumulative stolon length tends to stabilize around an equilibrium value of 230m².
- v) **Rhizoids** (Gk. roots) are rootlike extensions that absorb water, food, and nutrients. Unlike in vascular plants, Caulerpales do not have a root system composed of root cap and root hairs. Instead, regularly spaced rhizoid pillars descend vertically from the stolons. A few centimeters long, these pillars branch up into extremely thin filamentous rhizoids, that based on the substrate, can form a felt-like net penetrating through the substrate and thus stabilizing it and the algae.

How did it get there? (1/2)

Chronology:

Early 1980s: the striking properties of *C. taxifolia* were documented at the *Wilhelmina Zoo* (Stuttgart, FRG);
 1982: *C. taxifolia* was flushed into the Mediterranean;
 (Oceanographic Museum, Monaco)
 Since then: *C. taxifolia* covers some **13,000 hectares** of seabed;



Caulerpa taxifolia is a cold-tolerant marine alga that is widely used as a decorative plant in aquaria.

- Germany:** In the early 1980s, the curator of the tropical saltwater aquarium at the *Wilhelmina Zoo* in Stuttgart (FRG), noticed the exceptional properties of a bright green, beautiful green alga, *Caulerpa taxifolia*, used as tank decoration in the presentation of multicolored tropical fish. It was captively bred by the aquarium staff and exposed, for years, to chemicals and ultraviolet light. This exposure to abiotic stressors altered and switched on genes that have not been previously present, expressed or active in wild type strains found across the Pacific. The genetically altered seaweed, in contrast to other algae does not wither, grows with astounding vigor resisting cool water temperatures. Specialists quickly learned about these qualities, and public aquaria around the globe acquired cuttings.
- Monaco:** Eventually, in 1982, a sample of it found its way to the Oceanographic Museum in *Monaco*. The strain was inadvertently introduced into the Mediterranean Sea in wastewater from the Oceanographic Museum at Monaco, where it has now spread over more than 13,000 hectares of seabed. *C. taxifolia* forms dense monocultures that prevent the establishment of native seaweeds and exclude almost all marine life, affecting the livelihoods of local fishermen.

How did it get there? (2/2)

Since then *C. taxifolia* infestates the infra-littoral of:

- French & Italian Riviera;
- Strait of Messina;
- parts of Croatia;

Has even been spotted overseas (but was successfully eradicated due to the swift response of local authorities):

- Southern California;
- South Australia;

Global Invasive Species Specialist Group considered *C. taxifolia* as one of the **100 most Invasive Species**.



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Spread of *C. tax*:

- **1984:** a few meters deep, *A. Meinesz*, professor at the University of Nice-Sophia Antipolis, localizes a patch of *C. taxifolia* about a 1m² in size situated just the base of the Oceanographic Museum in Monaco;
- **1989:** repeated surveys reveal that the original site of infestation extends to cover an area about 1ha in size;
- **1990:** in summer of that year, the alga has spread along the southeastern coast of France. First outcrops are also spotted some 100km west of Monaco at Cap Martin and Toulon;
- **1991:** by now the radius of infestation stretches as far as 400km west of Monaco at St. Cyprien close to the Spanish border;
- **1992:** early that year and for the first time, the alga is spotted at sites opposing the westward drifting Ligurian current: e.g. Imperia (Italy); on the western front it continues its spread westward to hit the coast of the Balearic Island of Majorca (Spain);
- **1993:** the southeastward extension of the algae continues; sites of infestations are registered at the island of Elba (Italy) and as far south at Messina in the strait of Sicily (Italy);
- **1995:** eventually the algae reaches the Adriatic Sea; first sightings are reported at Malinksa and Stari Grad (Croatia);
- **1997:** by the end of that year, the tumor-like growth of individual patches of *C. taxifolia* carpets along the south-eastern coast of France have drastically increased in size and eventually merge to form huge meadows;
- **2000:** in ever more rapid events, *C. taxifolia* reaches the southern shores of the Mediterranean and is sighted at Sousse (Tunisia). In the very same year large patches of this invasive species is identified in the lagoon off San Diego (California, USA). At the same time patches of this invasive strain are sighted in Port Hacking, Lake Conjola and Careel Bay (in New-South Wales, AUS);
- **2001:** eventually other sites of infestation are identified at sites along the south-eastern coast of Australia: e.g. Narrawallee Inlet, Burrill Lake, Lake Conjola and Berringer Lake, Careel Bay, Pittwater, Lake Macquarie all in New South Wales and West Lakes & Port River in South Australia.
- **Among the 100 most invasive species:** Invasive species have been recognised globally as a major threat to biodiversity (the collected wealth of the world's species of plants, animals and other organisms) as well as to agriculture and other human interests.

<http://www.issg.org/database/species/search.asp?st=100ss&fr=1&sts=>

Properties & Impact of *C.taxifolia* (1/2)

Properties of the *C.taxifolia* mutant:

Habitat: grows on **Rocky, sandy, muddy** and particularly on **eutrophicated substrates**;

Temp.: survival range stretches from **7-32.5°C**;

Salinity: tolerates up to **38‰**;

Depth range: usually found at **3-35m**, but has been recorded at **100m** depth;

Toxicity: cocktail of **caulerpenyne** (CYN), oxytoxins, taxifolials and other terpenes;

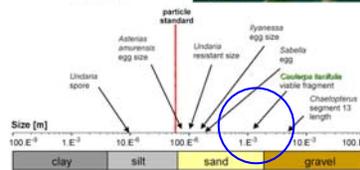
Pseudo-perennial growth pattern;



Viable fragments of *C.taxifolia* drifting in Mediterranean waters (BBC/News, 2001 - media)



Min. specimen size to maintain viability -information relevant to proposed particle sizes (McClay, 2001)



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Properties of *C.taxifolia*:

- **Habitat description:** found on a wide variety of substrates from rock, sand and mud to seagrasses. It is usually found in depths of 3-35 m, but has been recorded at 100m depths in the Mediterranean. The invasive aquarium strain is able to occupy up to 100% of the available substratum. Native populations in tropical waters are found on rocky reefs and seagrass meadows in sheltered or moderately wave-exposed areas in both polluted and pristine waters. The temperature range for the Mediterranean strain is 7°C - 32.5°C, while the maximum salinity is 38 ppt.

<http://www.issg.org/database/species/ecology.asp?si=115&fr=1&sts=>

- **Toxicity:** The cocktail of repellent toxins consists of **caulerpenyne** (CYN), oxytoxins, taxifolials and other terpenes. As CYN is the most predominant toxin, it is believed that toxicity is almost exclusively based on the acetylenic sesquiterpene caulerpenyne with a bis-enol acetate functional group.

Properties & Effects of *C.taxifolia* (2/2)

C.taxifolia affects

- microbial loop;
- marine flora;
- invertebrate fauna;
- infauna;
- fish fauna;

overall result:

- large-scale ecosystem change



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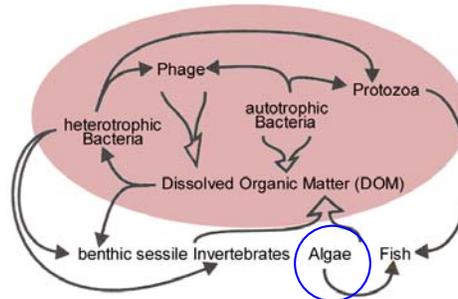
Impact of *C.taxifolia*:

- At any given site, this ubiquitous alga is able to colonize most if not all habitats. In the Mediterranean it has invaded *Posidonia* and *Cymodocea* seagrass beds, rocks with photophilic or sciaphilic alga, steep cliffs with sponges and sea fans, coarse and muddy sands, with a coverage of up to 100% maintained throughout the year. Today, more than 90% of the total cover of *C.taxifolia* is found in the north-western Mediterranean. During the first decade of the Mediterranean invasion, the alga's distribution pattern was rather more irregular and concentrated to zones where heavy development took place or in the vicinity of poorly treated wastewater outlets. The discharge of such huge amounts of raw sewage took place till 1981/82, and even as late as 1990, the main sewer outlet for Monaco discharged primary treated wastewater only 400m offshore. This remark is important as wastewater contains large quantities of phosphorous that in turn exhibit extremely low capacities to transform NH_4^+ into NO_2^- and NO_3^- - a fact that can still be found in the geo-chemical signature of the sediments. With the regression of the once abundant autochthonous flora (*P.oceanica* meadows) that started some 30 years before the invasion of *C.taxifolia* took off, it was an easy task for *C.taxifolia*'s to invade these territories.
- **General impacts:** *C.taxifolia* aquarium strain in the Mediterranean Sea is extremely invasive and smothers other algal species, seagrasses and sessile invertebrate communities. It does this by either out-competing them for food and light or due to the toxic effects of its caulerpenyne compounds. Its large monospecific meadows have vastly reduced native species diversity and fish habitat. Effects on humans are mostly related to the reduction of catches for commercial fishermen due to the elimination of fish habitat by *C.taxifolia*, although the entangling of nets and boat propellers with this weed also affect efficiency. Fish which are able to eat *C.taxifolia*, such as the Mediterranean bream (*Sarpa salpa*), accumulate toxins in their flesh that make them unsuitable for human consumption. *C.taxifolia* outcompetes the seagrasses *Posidonia oceanica* and *Cymodocea nodosa* in Mediterranean ecosystems.
- Economic impacts resulting from the cost of eradication included approx \$US 6 million spent in Southern California \$AUS 6-8 million in South Australia.

Microbial Loop & *C. taxifolia* (1/4)

Presence of *C. taxifolia* alters :

- DOM-concentration
- heterotrophic Bacteria composition;
- Protozoan community;
- and herbivorous fish community;



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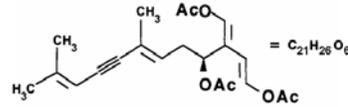
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Effect on microbial loop: Soft sediment bottoms are not only characterized by a high infauna and epibenthic fauna, but are directly coupled to the microbial association of the sandy substrate. Particulate organic material and plankton organisms in the surface water, are trapped and accumulate temporarily in shallow soft bottom sediment. Usually some of this carbon is available for consumption by benthic microbes in the system. However, the presence of an algal mat on otherwise unvegetated shallow soft bottoms considerably changes its ecosystem structure and functions. Rather than enabling a healthy microbial association to perform the nutrient conversion and especially under eutrophicated conditions, *C. taxifolia* takes over the "recycling activity". The altered nutrient dynamics of the sediment becomes evident in the net accumulation of organic matter. In the long term however, the organic enrichment leads to higher oxygen consumption that, together with the reduced water exchange, will result in decreased oxygen levels in both the water column and the sediment. The reduced oxygenation of the sediment causes the redoxcline to move towards the sediment surface further reducing the mineralization-capabilities of the microbial loop.

Flora & *C. taxifolia* (2/4)

Substitution of benthic sessile flora by *C. taxifolia* alters :

- Substrate conversion (sandy becomes vegetated);;
- **cocktail of toxins** such as taxifolials, caulerpenyne (CYN), and terpenes;
- fronds more toxic than rhizoids;
- stores the less toxic precursor **toxifolial-A**; CYN becomes activated once tissue damage occurs;
- antifouling properties of CYN;



Chemical structure of Caulerpenyne extracted from *C. taxifolia*
OAc = acetoxy = COOCH_3

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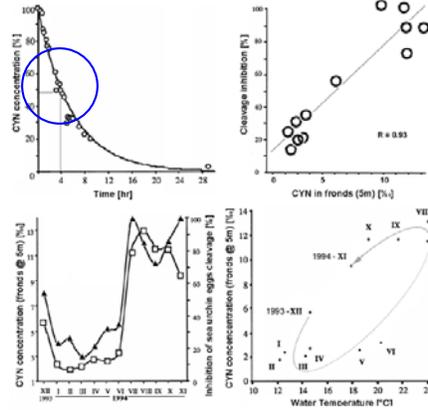
Effect on flora: Phytobenthic studies of highly infested areas around *Cap Martin* (Southern France) showed a drastic impoverishment of autochthonous communities. The creeping and erect axes of *C. taxifolia* shade off the light while its rhizoids trap and chemically alter the sediment. Most autochthonous algae tend to disappear quickly while crustose algae seem to be eliminated latest. The paucispecific *C. taxifolia* meadows tends to substitute for all sheltered algal infralittoral phytocoenosis which stands for a dramatic fall of richness and diversity of the littoral ecosystem.

Although Epibionts reduce the productivity of seagrasses by shading and reducing nutrient availability

Flora & *C. taxifolia* (2/4)

Substitution of benthic sessile flora by *C. taxifolia* alters :

- extreme growth in late summer (32mm of stolon per day);
- seasonal changes in toxic CYN concentration in fronds;
- CYN inhibits cleavage of the urchin *Paracentrotus lividus*;
- halftime C_{CYN} @ 4hours;



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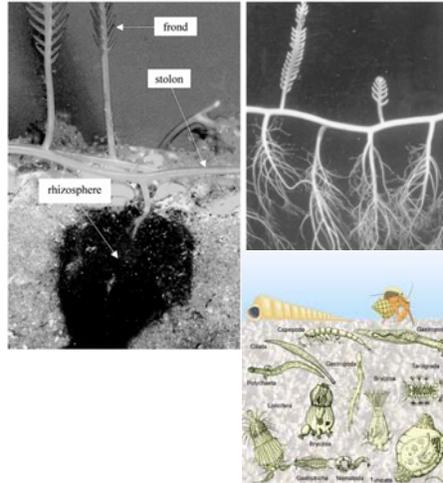
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Infauna & *C. taxifolia* (3/4)

Substitution of benthic Infauna (Interstitial) by *C. taxifolia* alters :

- renders substrate **anoxic**;
- thereby affecting infauna such as:
- Rhopodphyta
- Cnidaria
- Gastropoda
- Crustacea
- Echinodermata
- Acrania
- Telostei



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Soft sediment bottoms are characterized by a high infauna and epibenthic fauna production and play an important role as nursing and feeding habitat for many commercial fish species. Organic enrichment as such is already a cause for higher oxygen consumption. But *C. taxifolia* contributes additionally to an O₂-deprived sediment. The reduced oxygenation of the sediment causes the redoxcline to move towards the sediment surface, and the volume and surface area of the sediment available for efficient mineralization will be reduced. This is mainly due to lower decomposition rates during anaerobic compared to aerobic conditions. The reduction of oxygen in bottom water over the sediment under *C. taxifolia* affects benthic infauna. Furthermore, the reduced oxygenation of the sediment-water interface beneath *C. taxifolia* reduces the capacity of the denitrification process, i.e. the removal of dissolved inorganic nitrogen from the system. The organisms making burrows in the sediment usually facilitate through denitrification a transfer of nitrogen into the atmosphere – a process that comes to a halt in *C. taxifolia* meadows.

Particulate organic material (POM) and plankton organisms in the surface water, is trapped and can accumulate temporarily in shallow soft bottom sediment during the summer. Some of this carbon is available for consumption by benthic meio- and macrofauna in the system, and can either be borrowed in the sediment or transferred out of the system via migration of mobile species or predatory fish. The formation of *C. taxifolia* meadows on unvegetated shallow soft bottoms implies considerable changes in ecosystem structure and functions, many of which are important for generation of ecosystem goods and services. simply overgrows it.

Effect on Infauna: most characteristic endofauna/epifauna of mediterranean littoral sediments (2-30m) and those affected by a strong surge (up to 30m) include (Hofrichter, 2001: 393)

- Rhopodphyta: *Lithophyllum racemosus*;
- Cnidaria: *Hydractinia echinata*;
- Scaphopoda: *Dentalium vulgare*;
- Bivalvia: *Cardium tuberculatum*, *Diplodonta apicalis*, *Dosinia exoleta*, *Tapes rhomboides*, *Tellina pusilla*, *T. crassa*, *Venus casina*, *V. fasciata* ;
- Gastropoda: *Aceton tornatilis*, *Nassa mutabilis*, *N. pygmaea*, *Neverita josephina*;
- Crustacea: *Anapagurus breviculaetus*, *Cirolana gallica*, *Idothea linearis*, *Eocuma ferox*, *Macropipus barbatus*, *M. pusillus*, *Thia polita*;
- Echinodermata: *Astropecten* spp., *Echinocardium fenauxi*, *Ophiopsila annulosa*, *Sphaerechinus grannularis*;
- Acrania: *Branchiostoma lanceolatum*;
- Telostei: *Callionymus belenus*, *Bobius microps*, *Gymnammodytes cicereillus*;

Effect on Epifauna: the most common of the mediterranean littoral coast include (Hofrichter, 2001: 396)

- Polychaeta: *Arenicola marina*, *Sabella pavonina*, *Hyalinoecia fauveli* and other sessile or burrowing species of the families: Aphroditidae, Nephthyidae, Glyceridae, Eunicidae, Orbiniidae, Spionidae, Capitellidae, Oweniidae;
- Gastropoda: Bullomorpha;
- Bivalvia: *Pinna*, *Cardium Venus*, *Scrobicularia*, *Tellina*;
- Scaphopoda: *Antalis inaequicostatum*, *Pseudoantalis rubescens*;

Fauna & *C. taxifolia* (4/4)

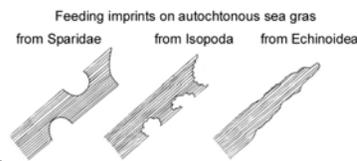
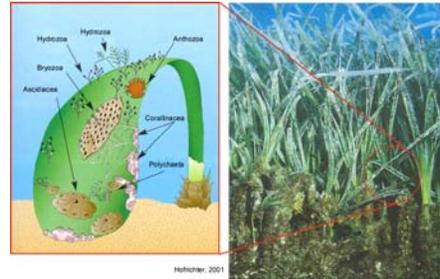
Substitution of benthic Invertebrate fauna by *C. taxifolia* alters :

- epiphytic/epizootic growth of fronds almost inexistant when compared to autochthonous flora;

antifouling properties of CYN minimizes

- grazing (toxic to grazers);
- substrate availability (i.e. fronds);
- deters herbivorous fish;
- increased mortality rates on potential predators (starvation);

Feeding traces on autochthonous flora



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Effect on Epiphytes:

Corallinacea: *Fosliella*;

Anthozoa: *Bunodeopsis*, *Paractinia*;

Hydrozoa: *Aglaophenia*, *Ophelia*;

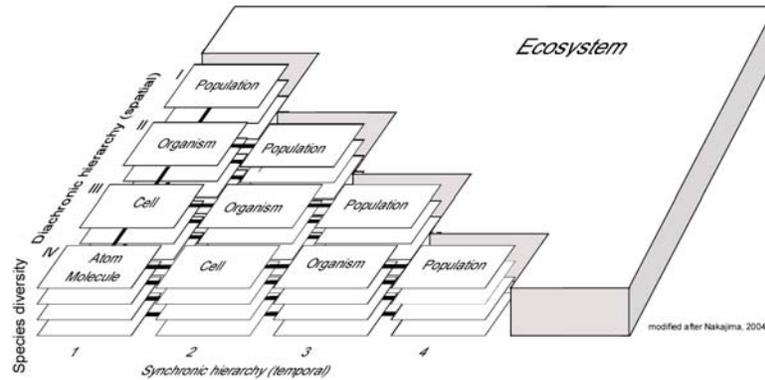
Polychaeta: *Spirorbis*;

Ascidiacea: *Bryozoa*;

Effect on fauna: A shift to *C. taxifolia* meadows alters the quality and function of these habitats as nursery and feeding grounds for commercial fishery species.

- **invertebrates:** it was observed that this invasive species suffocates numerous white Gorgonians *Eunicella verrucosa* at depths beyond 40m. Scientists analyzed *C. taxifolia*'s effect on three important groups of invertebrates itself staple food for carnivorous fish: i.e. polychaetes, molluscs and amphipods are quantitatively and qualitatively dominant groups and at the same time exhibit varied types of trophic, reproductive, and dispersion strategies. Based on a low sampling effort, scientists have focused on results obtained by pooling the four seasonal samples at each location with the result that the numbers of individuals of mollusca, amphipoda and polychaeta in *C. taxifolia* meadows were greatly reduced.
- **fish communities:** The objectives of some studies done so far were also done to quantify the consequences of this expansion on fish assemblages. It was feared that the bright color pattern of *C. taxifolia* might change predation pressure of carnivores feeding on herbi- and carnivorous fish communities; in fact fish color pattern is believed to serve three main functions: thermoregulation, communication and antipredator adaptation and are the results of selection pressures on the genetic structure of populations. Color patterns represent a good tool in understanding the adaptive mechanisms of a species to its environment.

Ecosystem Complexity (1/4)

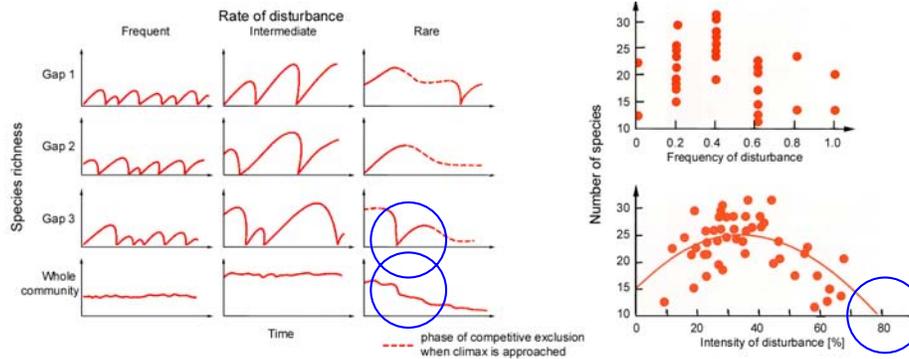


Substitution of benthic vegetation by *C. taxifolia* alters, i.e.:

- *Posidonia*, *Zostera*, *Cymodocea*, among others;

We need to be aware of that even if action is taken today and we manage to decrease eutrophication there seem to be a momentum within the system that sustains already established *C. taxifolia* meadows. Backed by a persistent parent colony new territories can be easily and regularly invaded several times (if previous attempts were less successful). The time it will take to return back will, thus, depend on the resilience of the algal dominated state. In this case resilience is an unwanted character of the system as it locks it into a state that is likely to have a relatively low value for society.

Ecosystem Complexity (2/4)



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Intermediate Disturbance Hypothesis (IDH); Diagrammatic representation of species richness versus time (left) at three frequencies of disturbance. The Relationship between species richness and disturbance-frequency as well as intensity is shown on the right. Disturbances open up gaps that lead to reasonably predictable species sequences. Early species are good colonizers and fast growers, whereas later species can tolerate lower resource levels and grow to maturity in the presence of early species, and eventually even outcompeting them. Begon et al., 1996

Gaps: represent geographically limited areas; here in which *C.taxifolia* is first established and gradually makes its way into neighbouring "gaps";

- A basic principle of ecology, according to Harvey & Hallett (1997), is that natural complex systems are generally stable and are able to return to their equilibrium state after a disturbance.

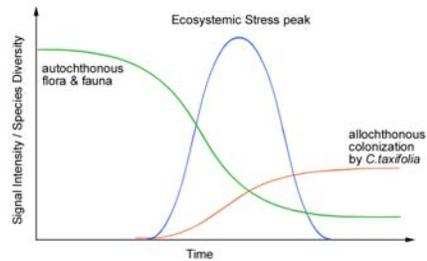
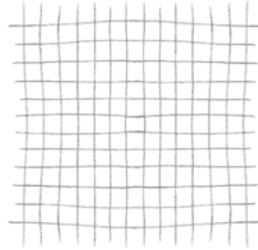
Resilience is the ability of a social-ecological system to undergo, absorb and respond to change and disturbance, while maintaining its functions and controls. The definition of resilience includes three equally important aspects, which *C. taxifolia* fulfils all of them:

- 1) the ability of the system to resist a disturbance so that it is not overwhelmed, but instead retains its functions;
- 2) capability of the system for self-organization (endogenous reorganization);
- 3) the ability to learn from and incorporate disturbances (mechanisms for adaptive capacity).

The emergence of *C.taxifolia* covered coastal zones indicates that many shallow systems have lost, or lowered their resilience. The shift to an algae dominated state and its persistence are most likely due to

- 1) increase loading of organic material;
- 2) build-up of sediment nutrient pool available for algae growth, and
- 3) increased pool of algae regeneration material in the sediment. Thus, the algae being produced creates **positive feedbacks** that keep the system locked in the new system state.

Ecosystem Complexity (3/4)



Web of Life: every knot can be considered to represent a species

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Web of Life: with the loss of knots, the mesh-size of the net increases, thereby decreasing the absorption capacities of the entire ecosystems to distress-events.

The originally present autochthonous flora/fauna is altered when the allochthonous *C.taxifolia* becomes the dominant floral species (e.g.: substituting *Posidonia*, *Zostera*, *Cymodocea*, *Ruppia*); thereby the prevailing ecosystem undergoes dramatic changes; these changes represent a huge stress momentum and fades as the new invading species becomes established. It results in large scale species change and loss of biodiversity.

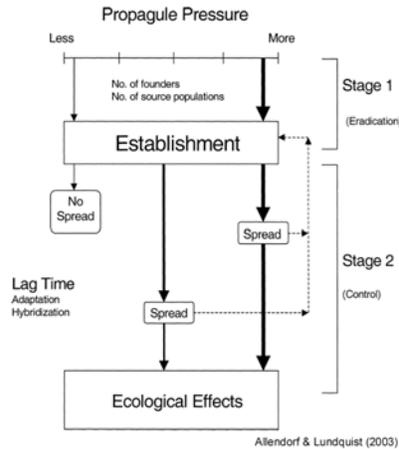
An increased supply of nutrients to the coastal ecosystem may have strong effects on the structure and function of the assemblages of benthic vegetation. It implies a shift in species composition from late successional perennial algae to fast growing "annual" species (**pseudo-perennial**);

Once established on the sediment the filamentous green algae will exhibit fast growth. Annual green algae not only have a high production but will also decompose rapidly. Parts of the meadow decompose during the productive season and as much as 50% of the annual production can be incorporated in the sediment when dead algae accumulate on the bottom.

Ecosystem Complexity (4/4)

Substitution of benthic Invertebrate fauna by *C. taxifolia* alters :

- economists pay little attention to the qualitative features of ecosystems;
- damages are discovered only when they are too large to reverse (insufficient ecosystem knowledge);
- deters herbivorous fish



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The two stages of invasion that generally coincide with different management responses. Propagule pressure is a continuum, with greater pressure leading to increased chance of establishment and spread with shorter lag times. If spread involves small groups of dispersing individuals, each group must be able to establish itself in a different area. Establishment or subsequent spread may be inhibited where groups reach the limits of particular environmental conditions.

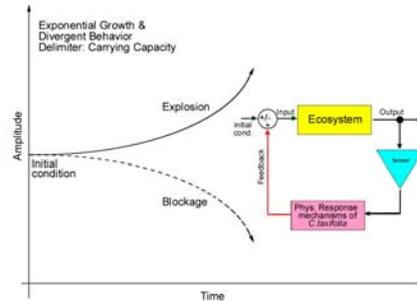
Allendorf & Lundquist; Population Biology of Invasive Species; Conservation Biology, Pages 24–30; Volume 17, No. 1, February 2003 (<http://www.blackwell-synergy.com/links/doi/10.1046/j.1523-1739.2003.02365.x/full/>)

- Most economists hat paid relatively little attention to the qualitative features of the global ecosystem.
- due to our insufficient knowledge about the whole ecosystem, damages are discovered only when they are too large to be reversed.

Conclusion

The aquarium strain of *C. taxifolia*:

- met the demand of aquarists – industry supported proliferation;
- its careless handling & nutrient enriched substrates facilitates dispersal;
- is very resilient – resists disturbance, capable of self-organisation,
- resists transfer to pre-*C. taxifolia* conditions – is prohibitively expensive;
- formation of *C. taxifolia* meadows implies considerable changes in ecosystem structure and functions;
- lowers ecosystem-resilience due to self-organizing pos. feedback loops;
- lowers commercial and recreational value of coastal environments;



Mille grazie per la vostra attenzione - Thanks for your attention

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- Human beings reform the environment through economic activities; on the other hand, economic activities decrease environmental resilience and increase the possibility of an environmental change in an discontinuous and irreversible pattern (Chu & Tai 2001).
- The above-mentioned vulnerability together with the fact that the probability of a major environmental shock increases as the ecosystem balance is damaged by human economic activities.
- When biodiversity is low, a large environment shock would make species extinct, due to the lack of species having a similar function. A full complement of species therefore provides the “buffering capacity” of the ecosystem.
- when a species over-specializes in adaptation, its ability to endure **environment shocks** will be very low, and its reliance on other species will increase
- **Resilience** is the ability of a social-ecological system to undergo, absorb and respond to change and disturbance, while maintaining its functions and controls. - *C. taxifolia* fulfils all of them;
- Ecosystems change drastically when sets of key species are lost - here by the substitution of autochthonous species (e.g. *P. oceanica*) with the invasion of the allochthonous species *C. taxifolia*;
- For *C. taxifolia*, not only may the new system state be undesirable from a societal perspective, but the possibilities to transfer the system back to a previous state may also be either very costly or even impossible (i.e. a highly resilient new state in *C. taxifolia*).
- The provision of ecosystems goods in terms of the production of fish species of commercial and recreational value in *C. taxifolia* meadows is significantly reduced, and replaced by non-commercial resident fishes and crustaceans.