MARINE AGRONOMY

Fundamentals of Good Agronomy Practices (GAP) for tropical carrageenan seaweeds

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FRONTISPIECE

Growing seaweed – simple concept –

just tie a piece on some string and hang it in the water ...

Catching fish – simple concept –

just tie a hook on some string and hang it in the water ...

... but you harvest no seaweed and you land no fish unless you apply the best techniques - in the best places - at the right times!

Fundamentals of Good Agronomy Practices (GAP) for tropical carrageenan seaweeds

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Perhaps the single most important lesson to be learned by direct experimentation is that the natural world, with all its elements and interactions, represents a complex system and therefore we cannot understand it and we cannot predict its behavior….

Managers interact with the system: they do something, watch for the response, and then do something else in an effort to get the result they want. There is an endless iterative interaction that acknowledges we don't know for sure what the system will do – we have to wait and see… Interacting with the natural world, we are denied certainty. And always will be.

Dr. Michael C. Crichton, 2008

PREAMBLE

As of 2013 almost all Kappaphycus and Eucheuma production has been from family farms and almost all production has served as raw material for the manufacture of carrageenan. Production of Kappaphycus has failed to reach levels of supply that adequately meet demand.

Although there will always be a need for major supplies of Kappaphycus and Eucheuma seaweed crops from small-holder operations there is also a growing need for farming of these crops to be undertaken in adequately capitalized integrated multi-trophic aquaculture (IMTA) systems and for processing to be undertaken using multi-stream, zero-effluent (MUZE) methods within satoumi seascapes. This requires the development of written agronomy protocols that can be developed and improved as experience, research and development lead beyond the empirical methods that prevail today.

During more than 40 years of working in seaweed farm development I have observed (and often participated in) many "failed" farm projects. Of course failure is inevitable for reasons clearly stated in the quotation (above) from Michael Crichton. The keys to eventual success are to make mistakes at as small a scale as possible; to learn from those mistakes; and to keep trying until you succeed.

The present monograph summarizes some fundamental aspects of cot+spin farming that I have learned from seaweed farmers, colleagues, scientists and "the school of hard knocks". I hope that they can help others to efficiently work through failed projects to successful conclusions.

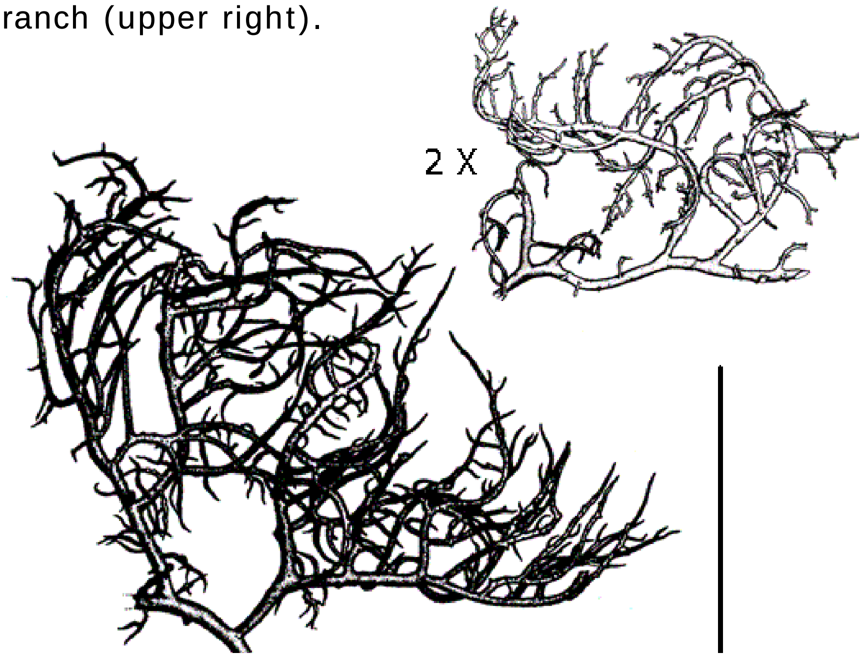
This monograph is the lead-in to sets of agronomy protocols that we have developed for particular projects. Please contact us if you have a project that needs such procedures.

Iain C. Neish, September, 2013, Makassar, Sulawesi Selatan, Indonesia

USE OF THE TERM "COT+SPIN" IN THE PRESENT MONOGRAPH

The present monograph is intended to apply to seaweeds (a.k.a. "marine macro-algae") with the classification: Eukaryota, Phylum Rhodophyta, Class Rhodophyceae, Subclass Florideophycidae, Order Gigartinales, Family Areschougiaceae, Genus Kappaphycus and Genus Eucheuma. In the seaweed trade Kappaphycus spp. is commonly called "cottonii" and Eucheuma spp. is commonly referred to as "spinosum". Collectively these genera can be referred to as cot+spin. For the sake of brevity the term "cot+spin" is used in the present monograph to refer collectively to Kappaphycus and Eucheuma.

Plate 1. Kappaphycus alvarezii (cottonii of the trade) var. tambalang plant (lower left) and closer view of branch (upper right).



M.S. Doty drawing
Length of bar ca. 10 cm.

Plate 2. Eucheuma denticulatum (spinosum of the trade)

Drawing I.C. Neish after M.S. Doty; Length of bar ca. 10 cm. relative to image.)

1. RAGS TO RICHES

Tropical seaweed aquaculture is currently dominated by the production of red algal galactan seaweeds (RAGS). The RAGS are red seaweeds (phylum Rhodophyta) that serve as raw material for the production of hydrocolloids known as kappa carrageenan (from Kappaphycus), iota carrageenan (from Eucheuma) and agar (from Gracilaria).

By far the greatest potential for tropical seaweed farming is in the Coral Triangle, especially in Indonesia. RAGS cultivation began in the Coral Triangle forty years ago but as of 2012 production is strictly in the domain of small-holders.

Plantation-scale seaweed production should be a very profitable business with huge potential for growth but no company has developed this potential. The time has come for potential to become reality.

RAGS farms placed in coastal waters are fundamentally different from farms for terrestrial crops such as oil palm, sugar cane, cocoa, bananas and coconuts. Marine agronomy has similarities with terrestrial agronomy but the differences must be understood. Ill-founded extrapolations from land farms to sea farms can be a formula for disaster.

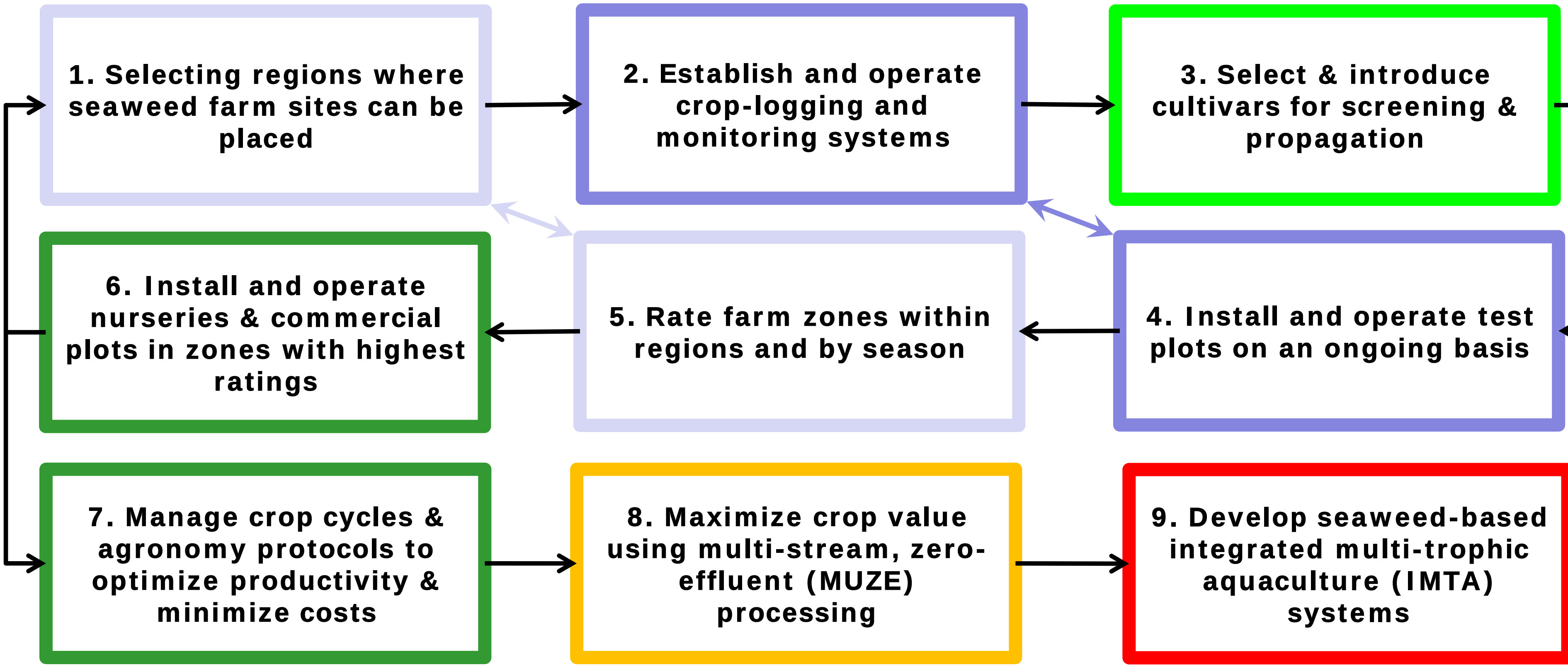
Features of RAGS farms in coastal waters that are worthy of note include these facts:

1. RAGS are marine macro-algae with fundamentally different structure and physiology compared to the vascular plants typically cultivated on land farms. Most RAGS are propagated as vegetative clones;
2. One hundred percent of RAGS biomass is useful crop. Tissues are not differentiated into fruit, stems, roots, leaves, etc. All biomass essentially has equal value;
3. RAGS can give you a compounded return on investment of 3 - 5 percent per day if farm modules are placed in "Goldilocks zones". This outstanding return has been realized by hundreds of small-holders who are diligent farmers located at the best locations;
4. RAGS placed on habitats in coastal waters depend on "mining the seawater" for survival and growth. No chemicals are applied to the crops in the sea although pre- treatments may be applied before planting;
5. Seawater is always on the move thanks to tides, wind and topography. Flow rates can be more than one kilometer per hour;
6. Water quality is generally dependent on seasonal weather patterns so farm sites may have to be shifted seasonally. RAGS farming can be very profitable if the best cultivars are placed in the best water during all seasons of the year;
7. RAGS quit growing and die if water conditions are not right; The ABC of farm prosperity is AIR (water), BIBIT (cultivar) and CARA (methods of agronomy);
8. Acquisition of planting rights can be a daunting challenge. A critical factor for farm success is the ability to find "Goldilocks zones" and then to secure the rights (on attractive terms) to plant in those zones. Tidal zones and inshore waters are generally public property that is highly valued for several competing uses.

2. SEAWEED FARM DEVELOPMENT IN SATOUMI SEASCAPES

The operation of cot+spin seaweed farms is an iterative process. Seasonal factors, farm expansion and market considerations may result in crop locations being moved among sites during each year of operation. Figure 1 shows a generalized set of steps toward establishing a cot+spin seaweed farm and also indicates how step development may be clustered into serial or overlapping development phases.

Figure 1. A generalized plan for establishing and operating cot+spin seaweed farms.



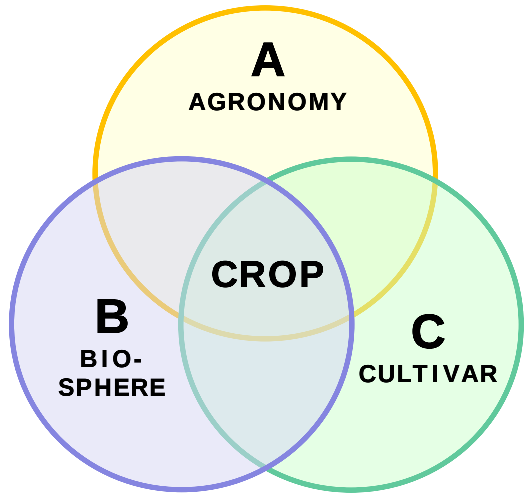
3. THE ABC OF SEAPLANT CROP BIOMASS PRODUCTION

The basis of cot+spin agronomy is the "ABC" factors shown in Figure 2.

Figure 2. The basis for seaweed farm operations is the "ABC" of crop biomass production**.**

A = AGRONOMY: The science and technology of farm management for production of seaplant crops

B = BIOSPHERE: The marine environments and habitat systems in which seaplants exist and grow



C = CULTIVAR: Robust, fast growing, high quality variety of seaplant that has been created or selected intentionally and maintained through cultivation for profitable production

C = CROP BIOMASS: Magnitude of living seaplant crop tissue available for making products.

The development of cot+spin agronomy is an outstanding example of farming that evolved from simple methods refined mainly by farmers in the sea. This phenomenon has led to current production on the order of 250,000 dry tons/yr from at least ten countries. More than 50% of world production is from Indonesia.

The commercial success of cot+spin farming is based on the fact that these plants produce vegetative cuttings (propagules) large enough to be economically planted and harvested individually. This insight surfaced during experimental farming conducted in the Philippines during the late 1960s and the early 1970s. The history of exactly "who discovered what" is rather muddled since many individuals and entities vie for status as pioneers in the development of cot+spin agronomy. Initial success occurred in the Philippines during the early 1970s as a result of activities variously undertaken by individual farmers; Dr. Maxwell Doty's University of Hawaii teams; the Philippine Bureau of Fisheries and Aquatic Resources (BFAR); various Philippine universities; and Marine Colloids Inc. (now FMC Biopolymer).

From the beginning cot+spin agronomy employed methods that attached individual cuttings to supporting structures. Such methods are fundamentally different from the agitated slurries of unattached cuttings used to produce pond-cultivated Chondrus and other smaller seaplants.

SPECULATION AND CONJECTURE

Marine agronomy, in its present form, is substantially based on speculation and conjecture. Most methods applied in commercial seaweed farms today have been developed by farmers in the sea. Methods of agronomy have been passed directly from farmer-to-farmer or have been passed on by trainers from non-government and government organizations. Training materials have generally been based on observation of methods utilized by successful farmers. Some good seaweed science (phycology) has been done on Kappaphycus and Eucheuma during the past fifty years but funding for applied phycological research on tropical red seaweeds has been sporadic and sparse. The industry has not been large enough to generate substantial funding from the public sector and weak protection for intellectual property (IP) has discouraged substantial investment from the private sector.

SOME R&D OPPORTUNITIES

Operation on a farm scale presents opportunities for R&D that can be integrated into crop logging and monitoring activities and also with scientific agronomy. Much of this R&D can lead to intellectual property that can be protected for competitive advantage. R&D opportunities include:

- Development of superior cultivars, especially for Kappaphycus and marine Gracilaria;
- Understanding cause-and-effect relationships between crop productivity, seawater characteristics and environmental parameters;
- Understanding the true nature of "ice-ice" and other maladies; development of cost-effective means for dealing with these maladies;
- Development of large-scale, low-labor habitat systems and agronomy protocols;
- Development of integrated multi-trophic aquaculture (IMTA) systems based on seaweed primary productivity;
- Development of multi-stream, zero-effluent (MUZE) process technology that starts with live crop from the sea.

Figure 3. drowning in a sea of untested hypotheses. For marine agronomy to progress there is a need for scientific research and development

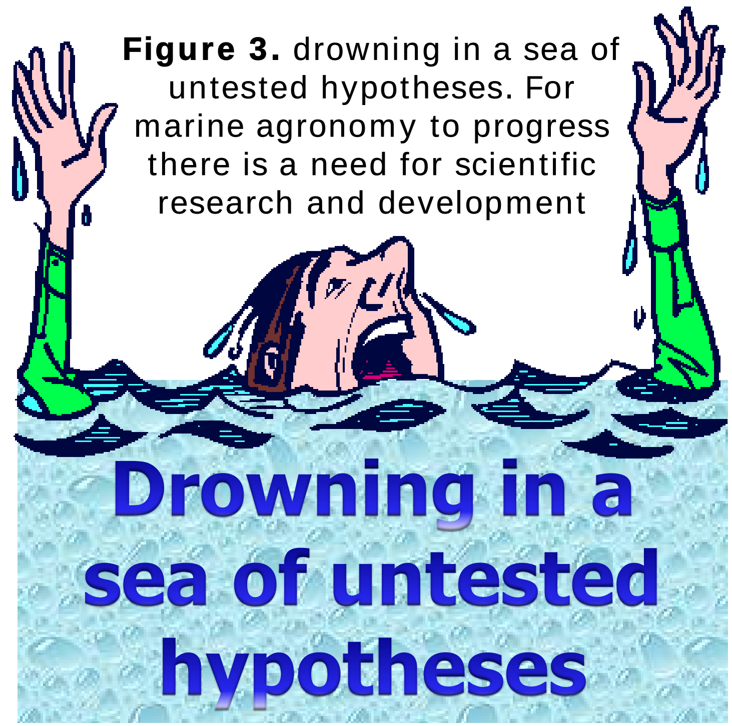


Image from Inkity

5. FINDING THE "GOLDILOCKS ZONES"

The success of commercial cot+spin sea farms is dependent on finding and/or creating "Goldilocks zones" where crop factors and environmental factors are "just right" for profitable farm development and operation (see Fig. 4).

CROP FACTORS

1. **Cultivars** are clones of cot+spin derived from vegetative propagation originating from a single seaplant thallus and with desirable characteristics for propagation in farm systems.
2. **Seawater biosphere** quality through time and space is a factor that will make or break any seaweed farm.
3. **Methods of marine agronomy** lead to successful, sustainable, profitable, nutritionally secured, efficient cot+spin crop production with least possible environmental degradation.

ENVIRONMENT FACTORS

1. **Enterprise factors** such as the agronomy and business management protocols that are used to operate the sea farm..
2. **Social factors** such as interactions with local populations, government agencies and value chain stakeholders.
3. **Geographic factors** including oceanographic conditions, weather, local topography and conditions impacting on logistics.

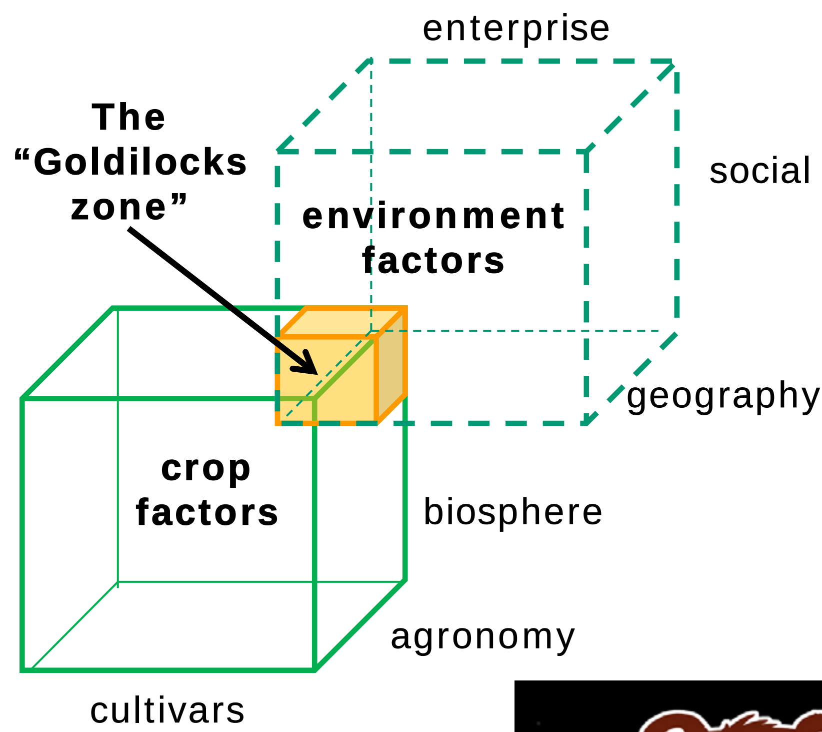


Figure 4. A "Goldilocks zone" is a set of conditions where everything is "just right" for farm success.

(Image at right by lpspalmer)

6. “MINING THE SEA” ALL YEAR AROUND

MINING THE SEA

Cultivating cot+spin in open coastal waters is actually a process of “mining the sea”. The farm operator does not add nutrients or other substances to the sea. Rather, cultivars are placed on habitat structures that are fixed in space and seawater flows past the crop as it is driven by natural laminar and turbulent flow. As seawater flows past, the crop “mines” elements from it. Some important aspects of this phenomenon are:

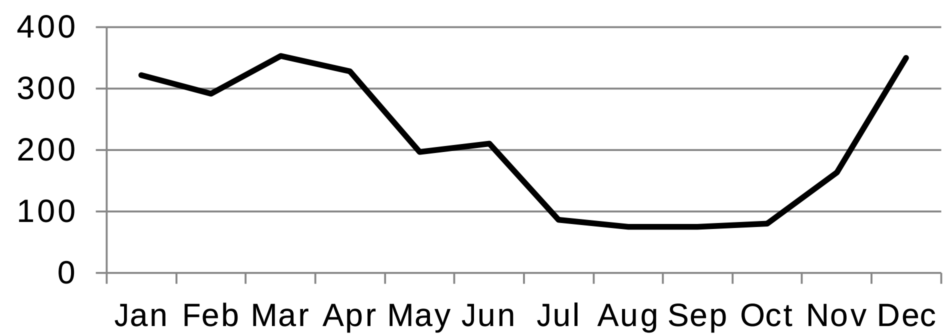
- seaweed nutrition depends not only on nutrient concentration but also on water motion.
- 85 to 98% of seasonal variability in crop productivity can be attributed to water motion.
- nitrogen is often a limiting nutrient but seaweed color reveals nitrogen status.
- seaweeds are extremely effective at concentrating trace elements that have value for agricultural nutrition
- seaweeds use carbon dioxide (CO_2) to make agar, carrageenan and alginates

Figure 5. (right). Monthly average mm of rain in Tual, Maluku, Indonesia. An example of a seasonal weather pattern.

SEASONALITY

Unfortunately there is no quick and easy way to predict seasonal shifts in crop productivity within and between planting zones. Optimal farm operation results from years of research, experience, learning and innovation. In order to arrive at optimal farm protocols it is necessary to:

- Gather and analyze crop logging data from monitoring stations, test plots and production plots;
- Undertake research and development to replace speculation with tested hypotheses;
- Seek geographical and seasonal correlations between environmental parameters and crop productivity or quality;
- Maintain constant vigilance of test plots and production plots with a view toward shifting plantings away from the least productive zones and toward the most productive zones on a “real-time” basis.



7. LARGE COMPARED TO SMALL OPERATIONS

The term "agronomy" is derived from the Greek *agros* (field) and *nomos* (manage).

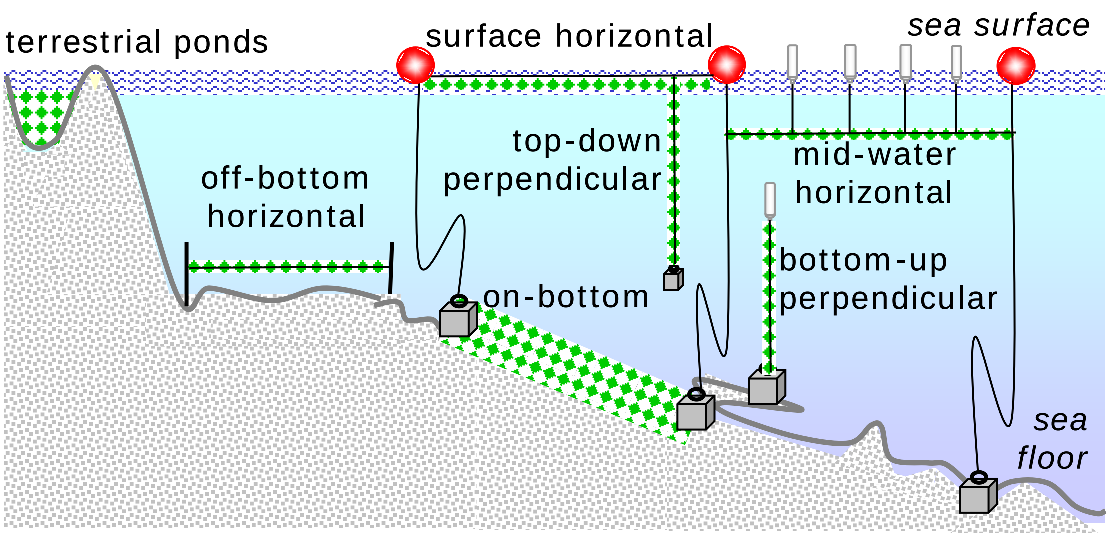
Marine agronomy is the science and technology of water and crop management in the sea.

Marine agronomy is more fully defined as successful, sustainable, profitable, nutritionally secured, efficient seaplant crop production with least possible environmental degradation.

Good agronomy practiced by small-holder farmers is sometimes referred to as "tender-loving care" or "TLC".

Plate 3. The best fertilizer is the farmer's reflection on the water… this an enduring principle of marine agronomy.

Figure 6. Some examples of seaweed habitat-system positions and orientations.



Large-scale seaweed farms must complement "TLC" with structured sets of agronomy protocols that are incorporated into professionally operated management systems.

In seaweed farms crops are managed within habitat systems that are installed in natural environments. A variety of possible habitat types is illustrated in Fig. 6.

8. ELEMENTS OF SEAWEED GROWTH

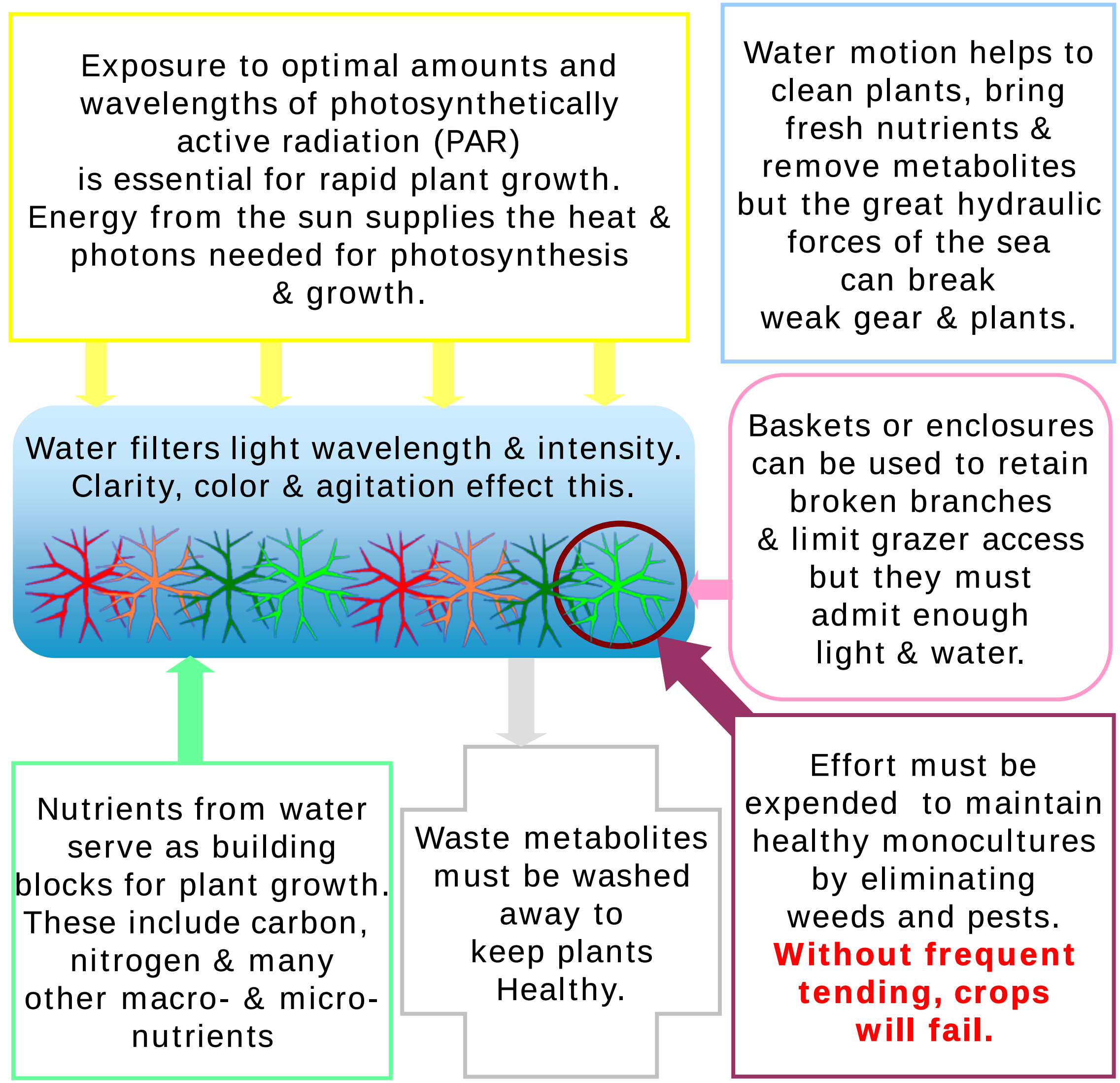
Agronomy methods must be developed with a clear understanding of what seaplants need in order to grow Note that seaweeds differ from sea animals in in these important ways:

1. **They get all their nutrients from seawater flow**;
2. **They must absorb photons** in order to photosynthesize and grow;
3. **They utilize carbon dioxide and generate oxygen (**the opposite of animals);
4 **Nitrogen compounds of the type excreted by animals** are crucial nutrients to seaweeds
5. **Unlike mobile animals such as fish, seaweeds** have no means of suspending themselves in the water column

These factors have important implications for the types of culture systems which must be used for raising seaweeds; including:

1. **Enclosures or suspension systems must expose** the plants to both light and water flow so large volume enclosures similar to fish cages cannot be used
2. **Plants must be separated and suspended by the** use of physical structures (e.g. cages or ties on ropes) and/or applied force (e.g. air and paddle agitators).
3. **Plants and animals can be combined in properly** designed IMTA systems to their mutual benefit

Figure 7. A schematic summary of some elements of seaweed growth in farms.



9. ELEMENTS AND FUNCTIONS OF FARM MANAGEMENT

ELEMENTS

People... The social environment in which a seaweed farm undertakes functions including stakeholders such as owners, employees, suppliers, buyers and government officials.

Environment... Interactions with the physical environments of seaweed farms - especially maximization of productivity and minimization of adverse impacts

Habitat... Development, construction and operation of the physical structures and agronomy systems that comprise seaweed farms.

Crop... The population of seaweed cultivars that comprise farm populations.

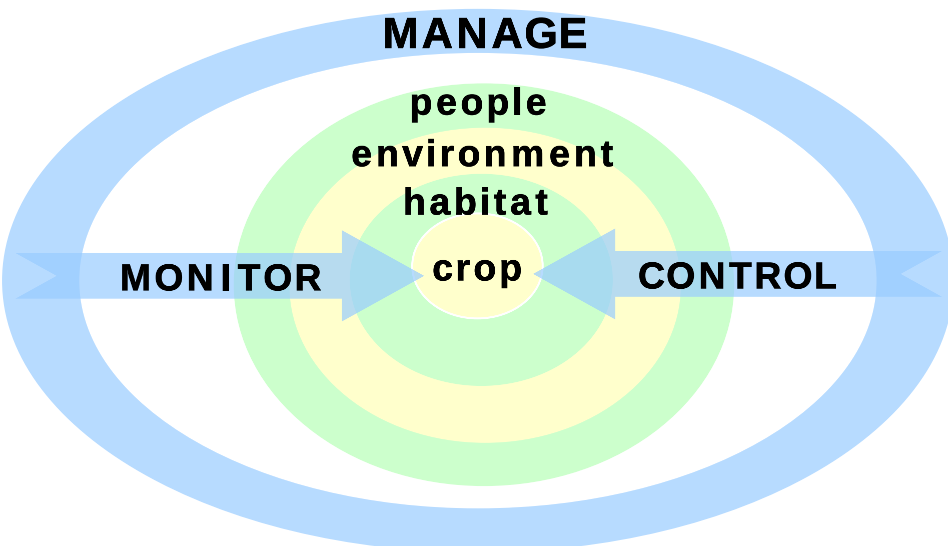


Figure 8. Elements and functions of seaweed agronomy systems .

MONITORING FUNCTIONS

People... farm managers and staff must maintain vigilance in the face of changing crop conditions.

Environment... Measure, record, analyze and utilize data pertaining to meteorological and oceanographic parameters that impact on crop productivity.

Habitat... Oversight and inspection leading to preventative maintenance of farm structures and equipment

Crop... Operate a comprehensive system of test plots and crop logging systems.

CONTROL FUNCTIONS

People... Operate effective training and management systems for farm managers and staff. Minimize the use of unskilled labor.

Environment... Ensure that the crop is always placed at the best possible locations. Pro-actively minimize negative environmental impacts and maximize positive impacts

Habitat... Operate farm structures and equipment using optimal operational protocols and automated control systems

Crop... Optimize cropping and processing cycles and procedures.

10. ENERGY AND MATERIALS EXCHANGE

Seaweed farm placed in seashore habitats become a component of complex energy and materials cycles that already exist in endemic, natural ecosystems. It is essential for effective farm management that interactions with endemic ecosystems be understood.

The metabolic processes of seaweed crops utilize energy, materials, water, nutrients and gases to produce biomass and metabolites that impact on other organisms as illustrated in Figure 9.

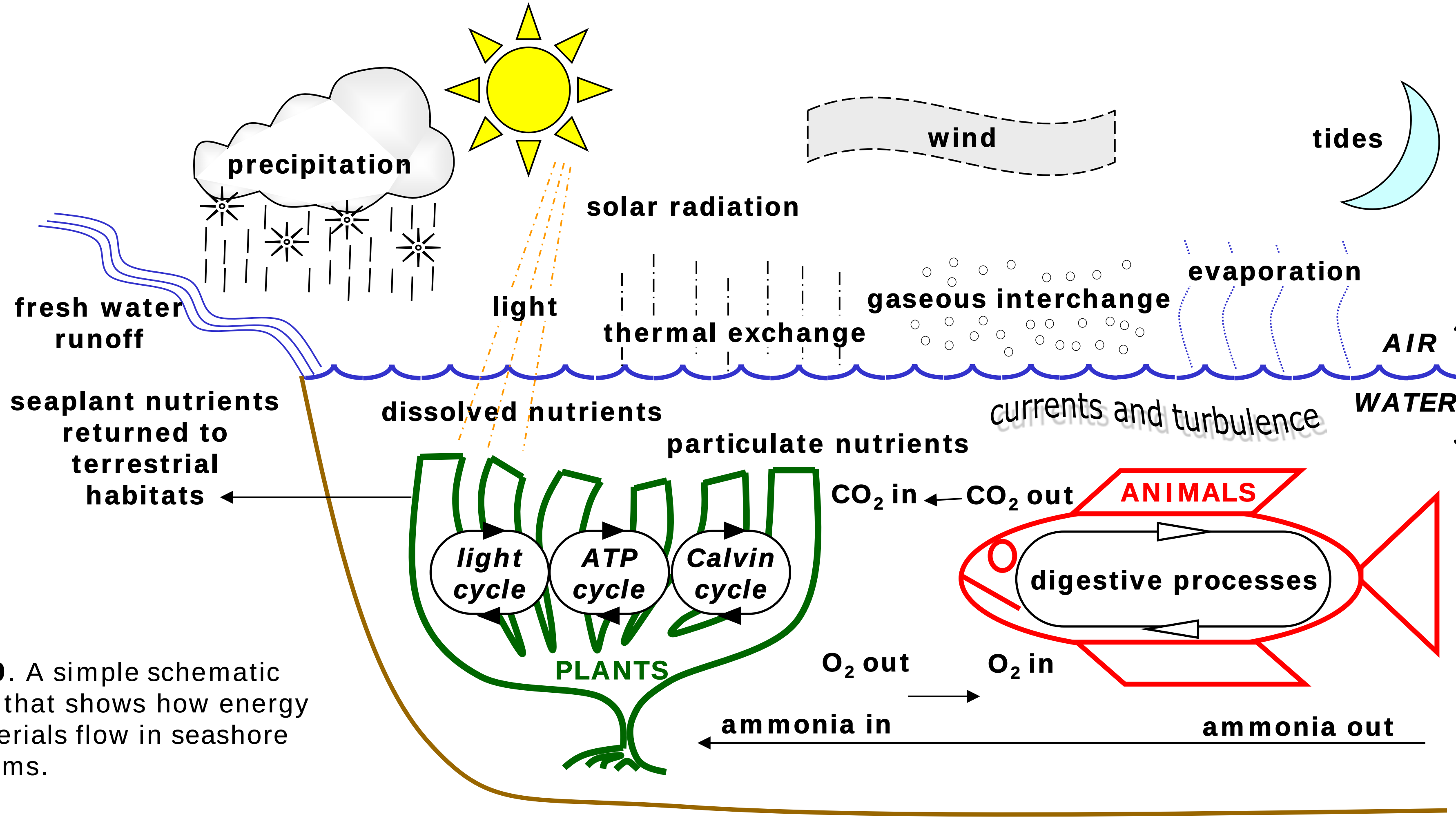


Figure 9. A simple schematic diagram that shows how energy and materials flow in seashore ecosystems.

11. ENVIRONMENTAL IMPACTS OF SEAWEED FARMS

Minimizing environmental impacts is a crucial aspect of sustainable farm management.

Five categories of impact relevant to cot+spin farms are:

1. Primary impacts caused by effects of seaplant metabolism and demography;

2. Secondary impacts caused by wastes or other impacts from post-harvest treatment and handling of crops;

3. Collateral impacts caused by activities that are directly related to farm operation including installation of habitat systems; trampling the sea floor; damage caused by the use of boats and vehicles; processing activities; and effluents;

4. Indirect impacts caused by domiciles, work places and process facilities placed near farms;

5. Direct processing impacts caused by effluents, solid wastes and other aspects of processing activities.

Plate 4. Tending crops from boats or on shore can minimize adverse farming impacts.

Negative farm impacts are most strongly associated with crop production on or very near the sea floor, namely:

1. Disruption of benthic community structure by removal of organisms and cutting of sea grasses.

2. Substrate abrasion and disruption caused by crops coming into contact with the sea floor.

3. Skewing of species composition caused by the introduction of new sets of ecological niches due to the physical presence of seaplants and farm habitats.

Positive impacts include increases in fish numbers; replacement of destructive activities by farming; and farmers gaining a sense of “stewardship” over coastal areas.

Impacts with either positive or negative effects include changes in primary production; and farms changing the nitrogen regime of the reef community.

Four ways of minimizing cot+spin farm impacts by using floating systems:

1. New habitat is created rather than existing benthic habitat being interfered with.

2. Substrate is placed into the water column where nutrients are most available.

3. Benthic communities are left intact. Planting cot+spin on or near the sea floor disrupts natural benthic communities and effects species diversity.

4. Crops can be tended using minimally destructive methods. The use of vessels, rafts and dive gear minimizes trampling of benthic habitats and organisms.