Aquaculture & Stock Enhancement:
A Solution for Protein from the Sea?
(Perspective on History, Pitfalls, & Progress of Aquaculture-Based Fisheries Enhancement)

Kenneth M. Leber
By 2050, the human population is projected to reach 9,200 million, which is within estimates of the maximum carrying capacity of the planet.

A fundamental question for science is whether it is possible to increase food production enough to feed a human population of that magnitude.
Ceilings to Agricultural Food Production

- Fresh water is increasingly being used for non-food production (biofuels, cotton, etc.)
- Climate Change will increase droughts
- Crop and grazing areas will have to increase 50% to 70% to feed the population expected by 2050 (but cannot)
- Yet crop area fell from .5 to .25 ha per capita from 1960 to 2000

- These trends show it is likely that Earth’s capacity to support the human population may be reached within the next 3 decades at population levels below currently proposed estimates.
The Rise of Aquaculture

- In contrast, aquaculture production has been doubling each decade and now provides 40% of aquatic food products.
- This 7%/yr growth far exceeds growth in land-based food production (2%/yr).

Duarte et al., 2009. *BioScience* 59:967-976
Mariculture is on the Rise

- As fresh water aquaculture is increasingly constrained, space & water availability will likely drive aquaculture growth towards mariculture in the long term.
- FAO forecasts mariculture will produce 54 to 70 million metric tons by 2020.

Duarte et al., 2009. *BioScience* 59:967-976
There are Some Major Bottlenecks: Feed, Space and Environmental Hazards Must be Overcome

- Maximum possible yield of fishmeal will cap mariculture production at 450 to 500 million tons/yr by 2040
- And agriculture substitutes will already have space and water constraints
- Aquaculture must close the production cycle as agriculture did in the 20th Century

Duarte et al., 2009. *BioScience* 59:967-976
Sustainable Aquaculture System Technologies

- Environmentally controlled tank systems
- Water recycle systems to conserve water resources and reduce environmental impact
- Integrated systems that produce both fish & plants
Marine Stock Enhancement Can Also Help Sustain Fisheries

- Types of Aquaculture-based fisheries enhancements
- Evolution of ‘Stock Enhancement’ science
- Key attributes of effective stocking
- Risks in implementing culture-based enhancements
- Opportunities and examples
- Take home messages
  - Aquaculture-based fishery enhancements must be better connected to fishery management
  - Optimization of release strategies is a critical step, often ignored, in maximizing
  - Assessment and adaptive management are crucial
Coupling Fisheries Management and Aquaculture

• **Culture-Based Fisheries – Types:**

  • **Stock Enhancement:** release of cultured organisms into wild populations to increase the natural supply of juveniles & optimize harvests by overcoming limitations in juvenile recruitment
  
  • **Restocking:** release of cultured organisms into wild populations to help restore severely depleted spawning biomass to self sustaining levels
  
  • **Sea Ranching:** recurring release of cultured juveniles into the ocean for harvest at a larger size (put-grow-take)

(Bell et al., 2008. Reviews in Fisheries Science, 16(1):1-9)
Historical Background: Evaluation of Marine Stock Enhancement

- **Fish Farming Begins in China ~ 5,500 years ago**
- **Stocking Marine Environments: Pre-Science Phase**
  - Aquaculture constraints to Evaluation
  - Assessment constraints to Evaluation
  
  **1880’s – 1980’s**

- **Pioneering Work to Quantify & Refine Stocking Effects**
  - Tsukamoto; Kitada; Tanaka; Yamashita; colleagues in Japan
  - Svåsand, Jørstad, Kristiansen and colleagues in Norway
  - Polovina; Stoner; Willis; Kent; Leber; Blankenship; Smith; et.al. in US
  - Bannister and colleagues in the UK
  - Støttrup and colleagues in Denmark
  - Qingyin Wang & Colleagues in China
  - Rimmer, Russell and colleagues in Australia; Bell in Solomon Islands
  
  **1990’s**

- **Recent Approach**
  - Improved Experimental Design; Quantitative Modeling
  - Comprehensive Assessment Efforts; 1st Stock Enhancement Courses
  
  **2000’s**
Science & Fishery Perspective
Driven Policy Development

• New research in early 1990’s generated WAS & EAS special sessions at their annual conferences -- on marine stock enhancement

• International Working Group on Stock Enhancement formed in 1993 in Spain
  – Platform Paper: Responsible Approach
    • Presented at 1994 AFS Symposium

• International Symposium on Stock Enhancement and Sea Ranching (ISSESR): every 4-5 years
“A Responsible Approach to Marine Stock Enhancement” *

(Spawned by Lee Blankenship, Devin Bartley, Don Kent, Ken Leber, Stan Moberly, Terje Svåsand, Katsumi Tsukamoto [and Rich Lincoln])

• **Stay Within Context of Fisheries Management Plan:**
  – 1. Prioritize Species for Enhancement
  – 2. Make Stocking Plan that Fits with and Helps Achieve the Goals of the Fishery Management Plan and Identify the Expectations

• **Develop Sound Enhancement Strategy:**
  – 3. Define Quantitative Measures of Success
  – 4. Use Genetic Resource Mgmt. to Prevent Deleterious Effects
  – 5. Use Disease and Health Management
  – 6. Consider Ecological, Biological, & Life-History Patterns
  – 7. Identify Hatchery Fish & Assess Stocking Effects
  – 9. Identify Economic & Policy Guidelines
  – 10. Use Adaptive Management

Responsible Approach to Marine Stock Enhancement: An Update

KAI LORENZEN,1,2,3 KENNETH M. LEBER,3 and H. LEE BLANKENSHIP4

1Program in Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, USA
2Division of Biology, Imperial College London, Silwood Park, Ascot, UK
3Center for Fisheries Enhancement, Mote Marine Laboratory, Sarasota, Florida, USA
4Northwest Marine Technology, Shaw Island, Washington, USA

Marine stock enhancement is a set of management approaches involving the release of cultured organisms to enhance or restore fisheries. Such practices, including sea ranching, stock enhancement, and restocking, are widespread, of variable success, and often controversial. A set of principles aimed at promoting responsible development of restocking, stock enhancement, and sea ranching has been proposed by Blankenship and Leber [American Fisheries Society Symposium 15: 167–175 (1995)], and has gained widespread acceptance as the ‘Responsible Approach’. Fisheries science and management, in general, and many aspects of fisheries enhancement have developed rapidly since the responsible approach was first formulated. Here we provide an update to the Responsible Approach in light of these developments. The updated approach emphasizes the need for taking a broad and integrated view of the role of enhancements within fisheries management systems; using a stakeholder participatory and scientifically informed, accountable planning process; and assessing the potential contribution of enhancement and alternative or additional measures to fisheries management goals early on in the development or reform process. Progress in fisheries assessment methods applicable to enhancements and in fisheries governance provides the means for practical implementation of the updated approach.

Risks of Stocking Cultured Fishes: What Can Go Wrong?

1. Replacement of wild with hatchery recruits, with no net increase in total stock

2. Unregulated fishing effort responses to presence of hatchery fish can cause overfishing of wild stock

3. “Overexploitation” of forage resource base for the stocked species beyond the carrying capacity of the release site

4. Genetic impacts on the long-term viability of the wild stock without careful control of broodstock genetics and domestication

It is critical to monitor the impacts of enhancement as the program develops to have evidence in hand about effectiveness

(Carl Walters & Steve Martell, 2004)
Most Enhancements are Weak in 5 Areas

- Lack of a clear fishery-management perspective
- Fishery stock assessments & modeling are integral to exploring the potential of stocking, but are found lacking in most stock enhancement efforts
- Establishing an institutional framework for enhancements is largely ignored
- Involvement of stakeholders in planning and execution of stocking programs is key from the start, but is rarely an integral part
- Adaptive management is not well integrated into enhancement plans
Enhancement Opportunities and Examples

- **Recovering a depleted fishery:**
  - Example: Hokkaido Scallops in Japan

- **Sea Ranching:** Zhangzidao Scallops in the Yellow Sea

- **Improving Existing Stocking Programs:**
  - Example: Hatchery Reform in US Pacific Northwest
  - Also, Research Programs: red sea bream, hirame flounder, red drum, snook, mullet, Chinese prawns*, cod* in Norway, N.Z. scallops, black bream in Australia, etc.

- **Supporting a fishery lost to habitat degradation:**
  - Example: Coho salmon in Japan

- **Stocking to enhance a well managed fishery:** Pacific Salmon?
Release Variables: Critical Uncertainties

- Critical Choices Managers of Hatchery Releases Need to Make
  - Tag type, tag placement, tagged proportion
  - Acclimation at release site
  - Size-at-release (SAR)
  - Season and tidal timing
  - Release habitat/microhabitat
  - Effects of interactions
  - Release magnitude

- Thus, use of pilot studies and adaptive management to optimize release strategies is key to understanding effects and effectiveness and efficiencies

Optimize Release Strategies To Maximize Survival
Virtually all aspects of enhancement research and management require the ability to identify released fish.
**Release Design**

**Day 1:** Stocked Acclimation pens

- NCO
- NCL
- CCL
- NCM

**Day 3:** Released snook from acclimation pens & also Stocked non-acclimated snook

- NCO
- NCL
- CCL
- NCM

**Result:** → Survival Increased ~100%

Pacific Threadfin in Hawaii
Releases at Kahana Bay

Seas: $P < 0.002^*$
SAR: $P = 0.392$
Inter.: $P > 0.006^*$

Release Microhabitat has a Large Effect on Snook Survival; for example:

(>12 MONTHS AT SEA)

Release Site (coded wire tag info)
Late summer/fall abundance decline

Post-release loss hatchery fish ~64-85%

Legacy from the Past

• Allure of a Quick Fix
  – If not implemented responsibly, enhancements may lull fishery managers into false confidence

• Isolation from the Fisheries Science Community
  – Often run with no connection to existing fishery management process, with hatcheries isolated and operating independent from stock assessment and fisheries monitoring programs

Enabling Factors for Expanding Successful Marine Enhancements

- Better connection to fishery management is essential
- Greater awareness among all stakeholders of the issues, pitfalls, progress and opportunities = more realistic expectations
- Use of Adaptive management is critical for managing enhancements for success and economic effectiveness
- Adapt the Responsible Approach to local circumstances
- Seek Assistance from established expertise in this field and the key associated fields