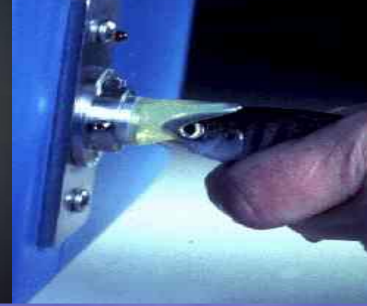




Investigations of stock enhancement potential of grey mullet in Hawaii:

rearing methods and pilot release-recapture results

Ken Leber, Lee Blankenship, Clyde Tamaru & Cheng-Sheng Lee

MOTE MARINE LABORATORY

NMT

Sea Grant University of Hawai'i

Oceanic Institute
An Affiliate of Hawai'i Pacific University

Marine Fisheries Enhancement Reform

- Stocking estuaries and oceans dates back to 1880's in USA and Norway, and earlier than that in Asia; <u>fell out of favor in 1950's in the USA</u> and replaced by harvest management
  - New marine stocking programs appeared in the 1970's but, as before, stocking without a 'Stock Enhancement' scientific framework
  - Prior to 1989, not one single paper in peer-reviewed scientific literature on the effects or effectiveness of stocking fishes, that spawn in seawater, into the sea

- ***Since 1989, progress in marine fisheries enhancement has occurred at two levels***:
- ***<u>Strategic</u> Advances** - **Adoption of a careful and responsible approach for conducting enhancements*** (aided by salmonid debates)
- ***<u>Scientific</u> Advances** – **Marine aquaculture / stocking impact / genetic risk / modeling enhancements / evaluating survival / improving release strategies***

"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])

- **Keep 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
  - 8. Use an Empirical Process to Define Optimal Release Strategies
  - 9. Identify Economic & Policy Guidelines
  - 10. Use Adaptive Management

(* Blankenship & Leber, 1995. Am. Fish. Soc. Symposium 15:67-175)

PDF is online at www.StockEnhancement.org/science/publications.html

‘Updated Responsible Approach’ (URA)

<u>Stage I: Initial appraisal and goal setting</u>

(1) Understand the role of enhancement within the fishery system
(2) Engage stakeholders and develop a rigorous decision making process
(3) Quantitatively assess contributions to fisheries management goals
(4) Prioritize and select target species and stocks for enhancement
(5) Assess economic and social benefits and costs of enhancement

<u>Stage II: Research and technology development including pilot studies</u>

(6) Define enhancement system designs
(7) Develop appropriate aquaculture systems
(8) Use genetic resource management
(9) Use disease and health management
(10) Ensure that released hatchery fish can be identified
(11) Use an empirical process for defining optimal release strategies

<u>Stage III: Operational implementation and adaptive management</u>

(12) Devise effective governance arrangements
(13) Define a management plan with clear goals and decision rules
(14) Assess and manage ecological impacts
(15) Use adaptive management

Kai Lorenzen

Lee Blankenship

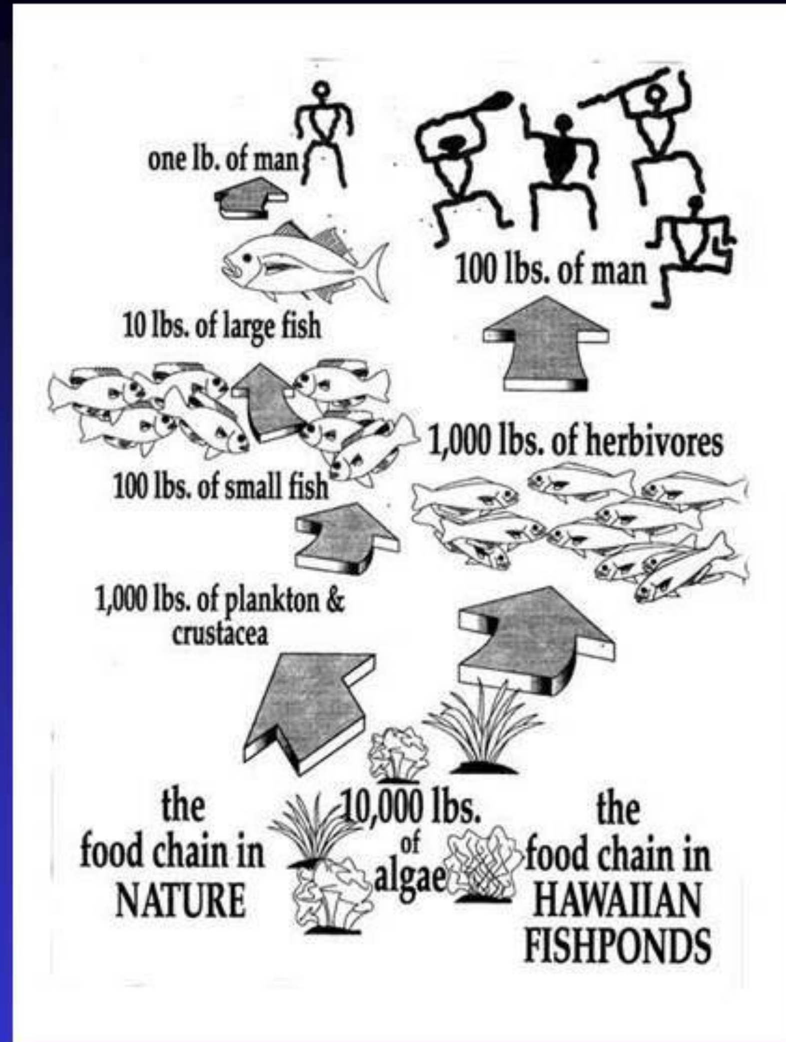
Lorenzen, Leber & Blankenship *Rev. Fish. Sci.* 2010

Testing Grey Mullet (Ama'ama) Enhancement Potential in Hawaii

Early Development of Hawaiian Aquaculture

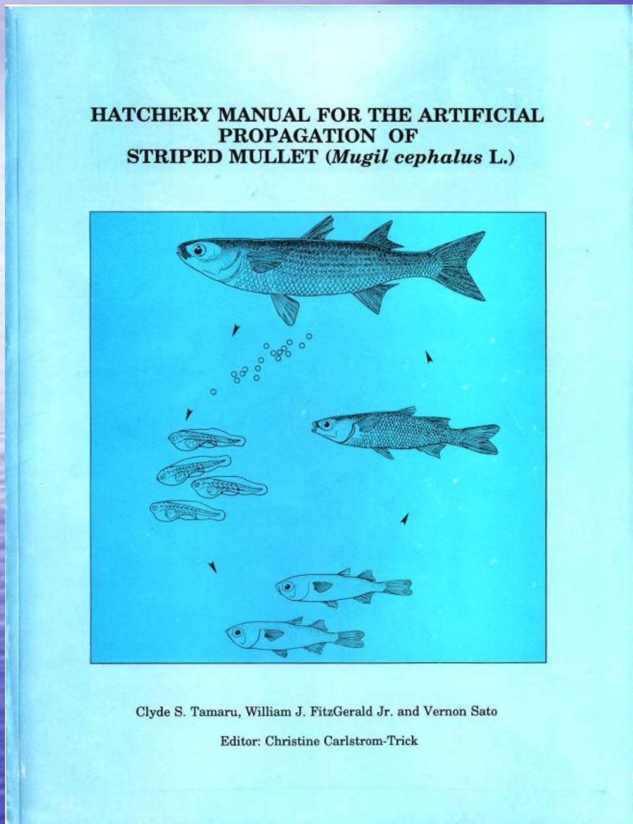
Ama ama, mullet, *Mugil cephalus*
430,115 lbs produced in 1901

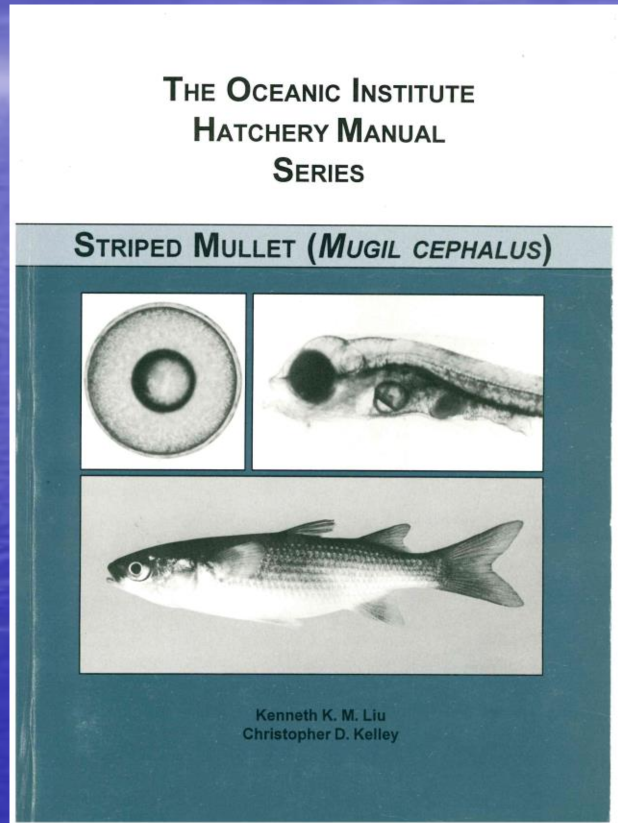
Awa, milkfish, *Chanos chanos*
224, 321 lbs produced in 1901



Hiatt, Robert W. 1944. Food Chains and the Food Cycle in Hawaiian Fish Ponds. Transactions of the American Fisheries Society, 74 (1944): 250-280

Advances in Mullet Aquaculture In Hawaii





Aquaculture, 91 (1990) 281–294
Elsevier Science Publishers B.V., Amsterdam

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Factors affecting intensive larval rearing of striped mullet, *Mugil cephalus*

Hiroki Eda[a], Ryan Murashige[a], Yoshioki Oozeki[b], Atsushi Hagiwara[c], Bryan Eastham[a], Paul Bass[a], Clyde S. Tamaru[a] and Cheng-Sheng Lee[a]

[a]*Oceanic Institute, P.O. Box 25280, Honolulu, HI 96825, USA*
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[c]*Nagasaki University, Graduate School of Marine Science and Engineering, 1–14 Bunkyo-Machi, Nagasaki 852, Japan*

(Accepted 30 April 1990)

ABSTRACT

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INTRODUCTION

Development of suitable feeding regimens for mass rearing of larval fish represents one of the last barriers to successful propagation of a variety of marine species. Most problems result from the relatively small mouth size of hatched larvae (Shirota, 1970) and their limited yolk reserves. This presents culturists with the difficult task of identifying an appropriate food type, quantity, and quality at initial feeding. Furthermore, the time when food is introduced to the larvae is a critical factor in the avoidance of early and irreversible starvation (Lasker et al., 1970).

Investigations on rearing larvae of the striped mullet (*Mugil cephalus*) have

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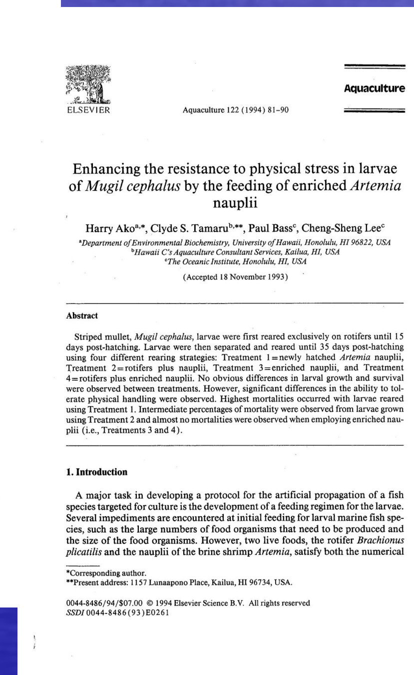

ELSEVIER

Aquaculture 122 (1994) 81–90

Aquaculture

Enhancing the resistance to physical stress in larvae of *Mugil cephalus* by the feeding of enriched *Artemia* nauplii

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Abstract

Striped mullet, *Mugil cephalus*, larvae were first reared exclusively on rotifers until 15 days post-hatching. Larvae were then separated and reared until 35 days post-hatching using four different rearing strategies: Treatment 1=newly hatched *Artemia* nauplii, Treatment 2=rotifers plus nauplii, Treatment 3=enriched nauplii, and Treatment 4=rotifers plus enriched nauplii. No obvious differences in larval growth and survival were observed between treatments. However, significant differences in the ability to tolerate physical handling were observed. Highest mortalities occurred with larvae reared using Treatment 1. Intermediate percentages of mortality were observed from larvae grown using Treatment 2 and almost no mortalities were observed when employing enriched nauplii (i.e., Treatments 3 and 4).

1. Introduction

A major task in developing a protocol for the artificial propagation of a fish species targeted for culture is the development of a feeding regimen for the larvae. Several impediments are encountered at initial feeding for larval marine fish species, such as the large numbers of food organisms that need to be produced and the size of the food organisms. However, two live foods, the rotifer *Brachionus plicatilis* and the nauplii of the brine shrimp *Artemia*, satisfy both the numerical

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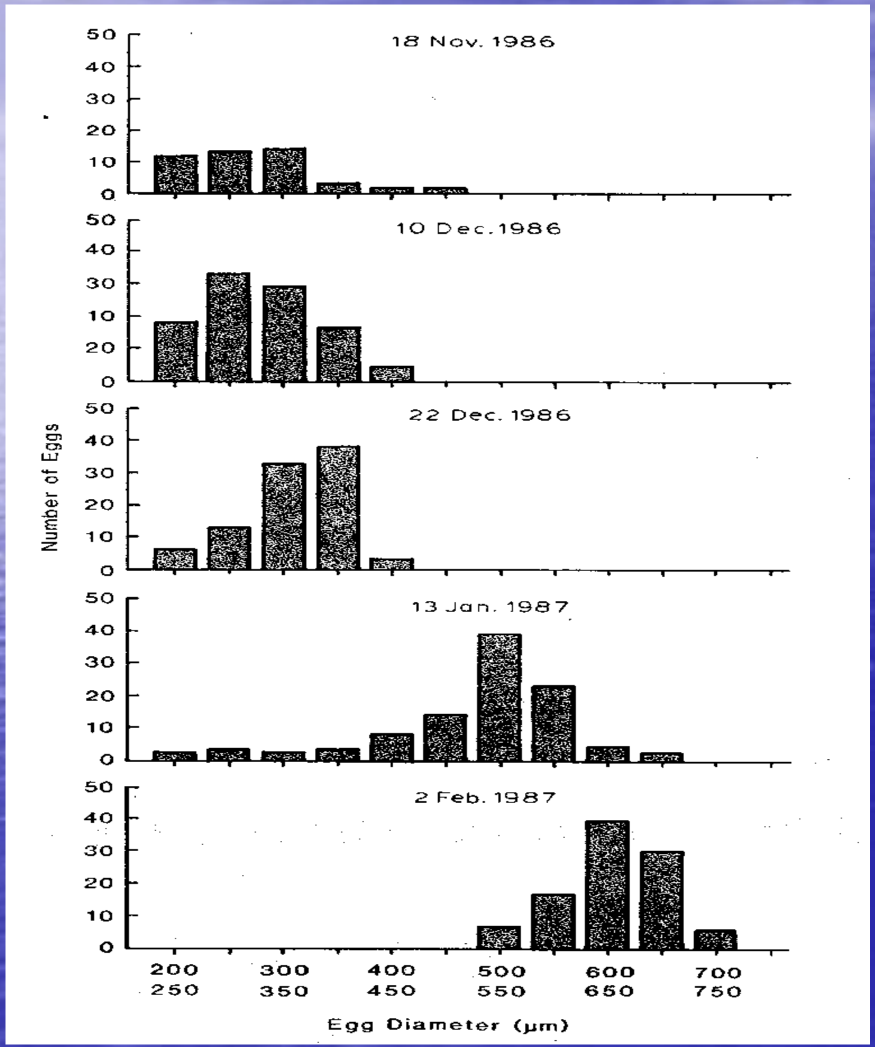
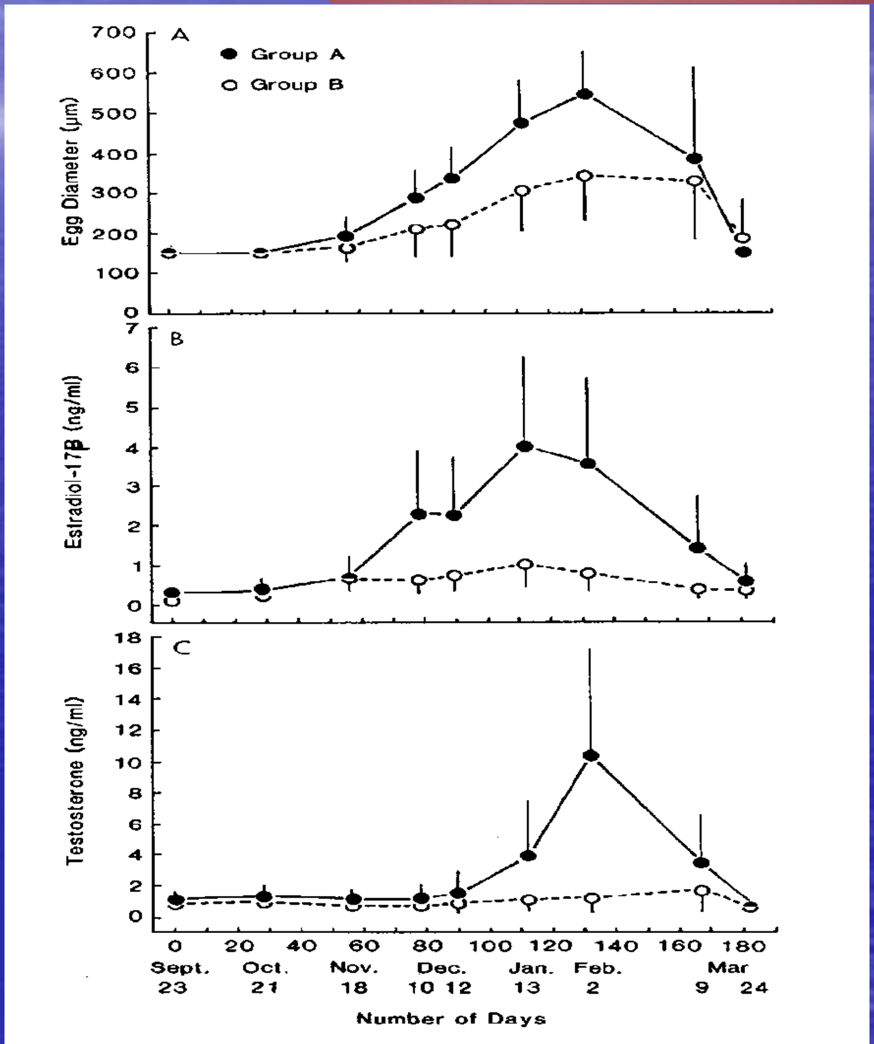
Changes in Oocyte Growth and Serum Steroid Levels in the Striped Mullet





Procedure For The Induction Of Maturation:

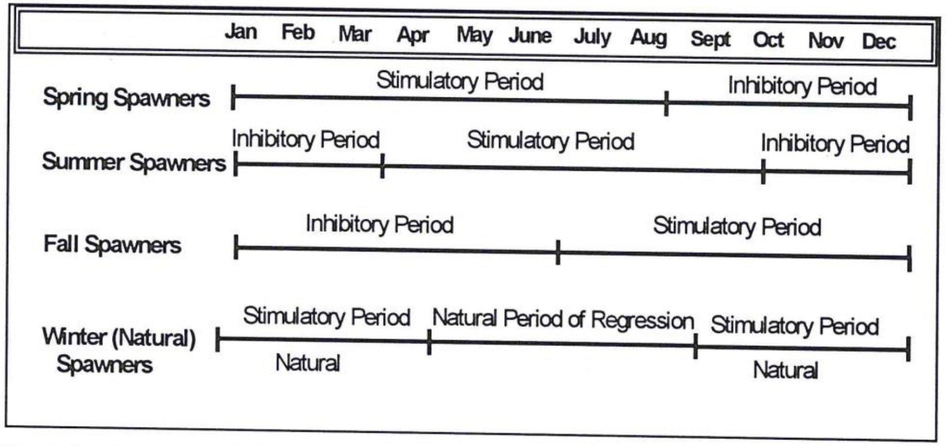


FIGURE 3. Annual schedule for year-round spawning.

dicting more precisely the time at which females will reach an average oocyte diameter of 600 µm:

$$\text{Ln (egg diameter)} = 4.96 + 0.014 \text{ (days)}$$

Off-Season and Year-Round Maturation

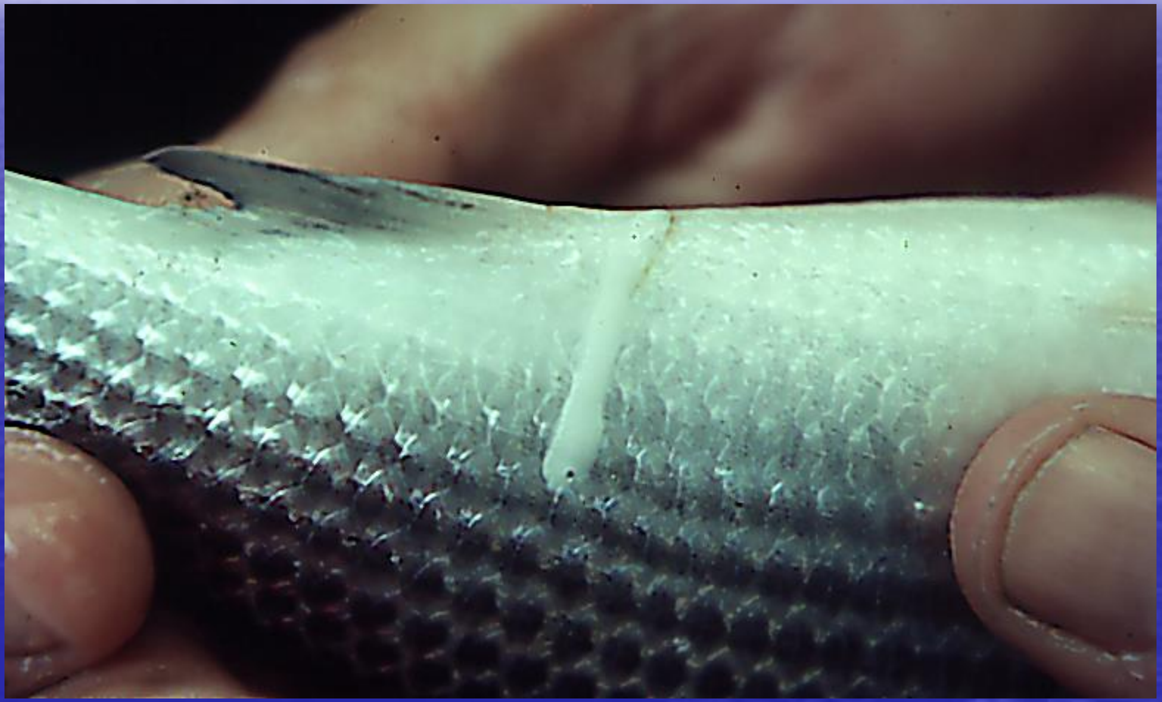
The capability to control the maturation cycle with photoperiod and temperature provides a hatchery with two options: 1) to produce fry only during the off-season when the price is higher and competition from natural fry collectors is minimal; or 2) to produce fry throughout the year during both the on-season and off-season which avoids hatchery down time. With some species of fish, the entire broodstock can just be placed under constant stimulatory conditions for continuous maturation. In other species, particularly those like the mullet which appear to require a "refractory period," the broodstock are divided into groups and sequentially placed under a cycle of stimulatory and inhibitory conditions. This technique is referred to as "phase-shifting" as each group has an on-season and an off-season which is out of phase with the natural cycle.

In Hawaii, OI has obtained year-round maturation and spawning with broodstock divided into one natural "winter" group and three phase - shifted groups: a "spring" group, a "summer" group, and a "fall" group. Each of the last three groups is subjected to similar stimulatory conditions (8-12 hours daylight and 20-26°C) and inhibitory conditions (14-18 hours daylight and 27-30°C), but at different times of the year (Fig. 3). During all but 10 weeks of the year, the broodstock are maintained in 30-ton outdoor fiberglass tanks, each fitted with a plastic hood (Photo 21) and a set of spotlights connected to a 24-hour timer to control photoperiod. A freshwater line allows salinity and temperature control, as freshwater at The Oceanic Institute is colder than seawater. The fish are stocked at a density of 1.5 fish/ton and at a sex ratio of 1:1.

The stimulatory period is 30 weeks. On the first day that a group begins this phase, the fish are staged, measured and weighed. Staging is repeated at weeks 6 and 12, and at three week intervals thereafter. During the first six weeks, the fish are maintained in 35 ppt seawater. From week 7 to 30, freshwater is added which reduces the salinity to 15-25 ppt and temperatures to below 26°C. Photoperiod is shortened to eight hours from

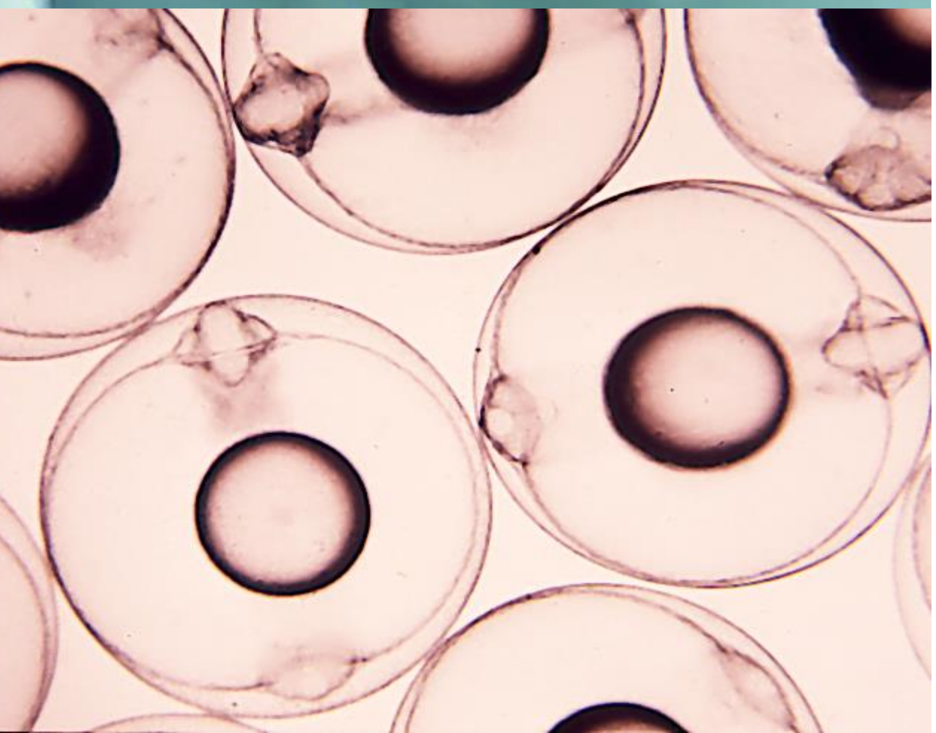
Procedure For The Induction Of Spawning: Step 1: Assess Gonadal Maturity

Ovarian Biopsy ♀



Presence of Milt ♂

Procedure For Induced Spawning:



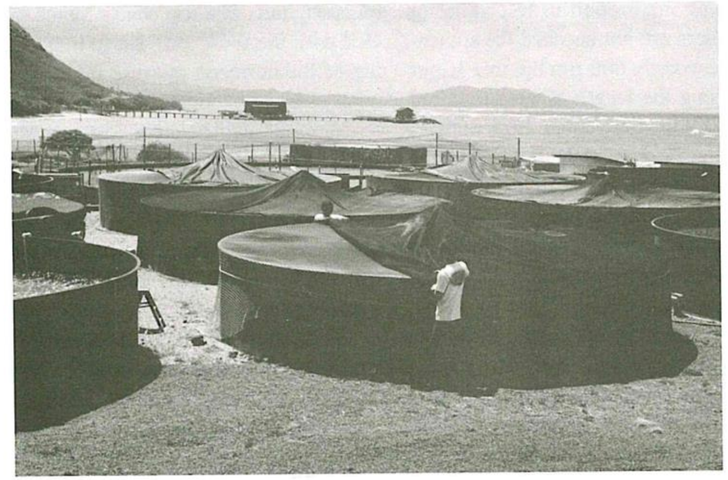


PHOTO 21. Outdoor maturation tanks with blank "hood" covering.

0815 to 1615. During this period, eggs will develop as if they were in normal winter conditions. They can then be induced to spawn with an acute hormone treatment (see "Induced Spawn" section) when the average egg diameter is 600 µm or greater.

The inhibitory period, which follows the stimulatory period, has a duration of 22 weeks divided into two phases: preliminary and final. The preliminary phase lasts for 12 weeks, during which the fish are placed under 18 hours of light (0400-2200) and normal 35 ppt seawater. Afterward, the 10-week final phase begins with the transfer of the fish to a 35-ton indoor tank fitted with artificial lights controlled by 24-hour timers and a 1-kilowatt submersible heater to raise the water temperature to 28°C. The lights are set to turn on at 0400 and off at 2200 (the same photoperiod as in the preliminary phase). The necessity of elevating temperatures in this final phase is currently being investigated. If unnecessary, the two inhibitory phases will be combined into a single 22-week phase of extended photoperiod (18 hours of light) and ambient water temperatures.

Hormonally Stimulated Maturation

At the present time, the FDA has not approved the use of any hormones for aquaculture. However, there are other countries which do not have these restrictions and studies are currently in progress which may lead to the approval of the use of LHRH-a and 17α-methyltestosterone in the U.S. Therefore, techniques to hormonally stimulate maturation and spawning in mullet are included in this manual.

LHRH-α Accelerated Females

As mentioned earlier, the growth rate of oocytes in the vitellogenic stage averages 7 µm/day. Therefore, the time required for a female to reach an oocyte diameter of 600 µm is two months. Females who begin this stage in November may reach full maturity, be induced to spawn and mature a second clutch of oocytes before the end of the natural season. This does not happen very often for a number of reasons. Some females are "slow

Adapted Japan's Larval Rearing

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Enriching Artemia Nauplii

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Release Variables: Critical Uncertainties

- **Use adaptive management** to decide the best choices for how to conduct stocking
  - Tag type, tag placement, retention
  - Acclimation at release site
  - Size-at-release (SAR)
  - Season and tidal timing
  - Effects of interactions
  - Release habitat & microhabitat
  - Release magnitude

Optimize Release Strategies

To Maximize Survival

- With this approach, stocked hatchery fish approach survival levels of wild fish; and stocking efficiency is maximized

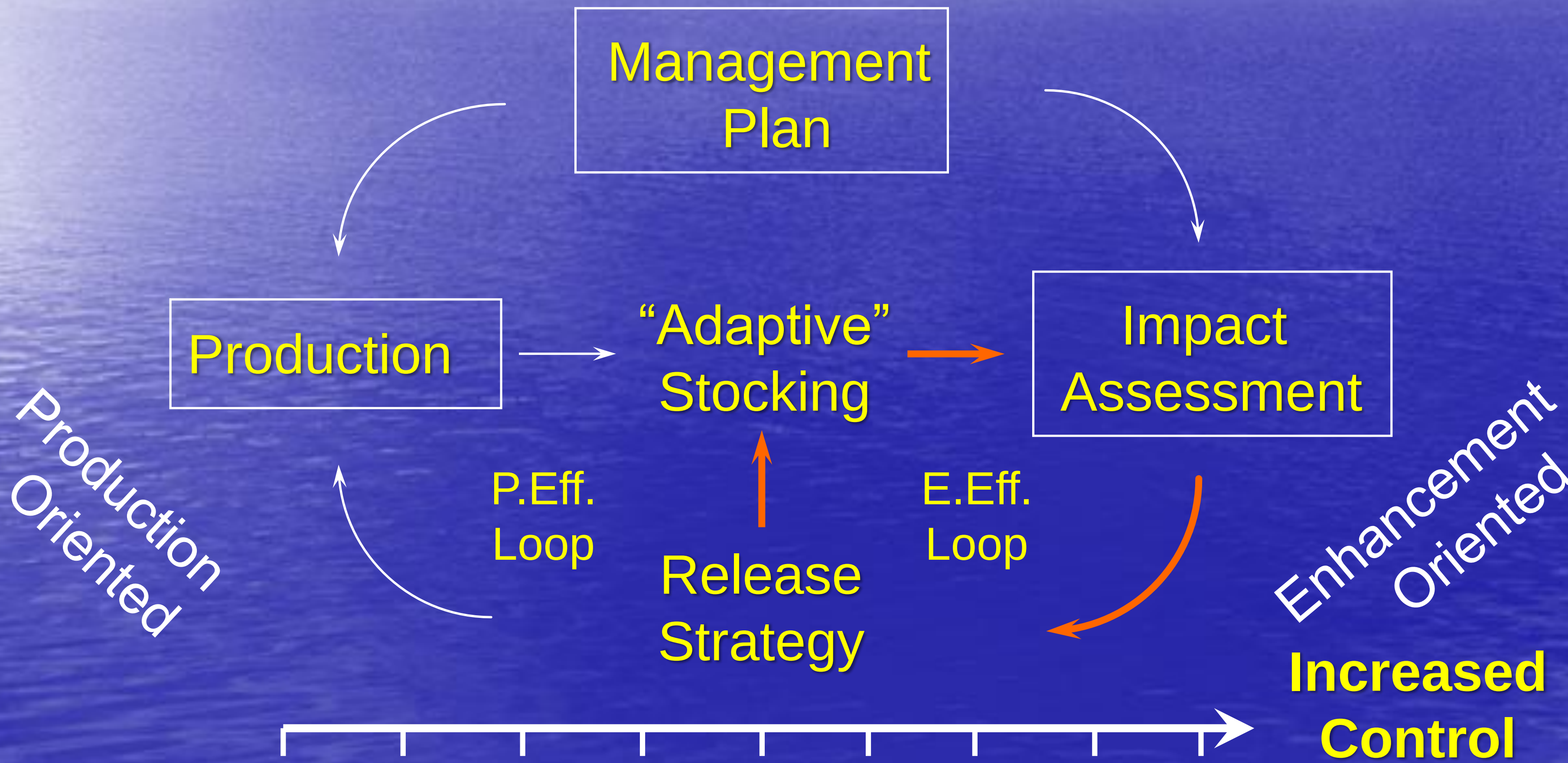
Compare Stocking Strategies to Maximize Survival

Pilot Releases

to Assess and Control Stocking-Strategy Effects on Short-Term Mortality

Adaptive Management is Crucial

Recognize the "Production - Enhancement" Management Dichotomy



(**Leber, 2002. Advances in Marine Enhancement: Shifting Emphasis to Theory & Accountability.** *In* Stickney & McVey)

Monitoring is Essential…

Rationale for Pilot Studies to Optimize Release Protocol

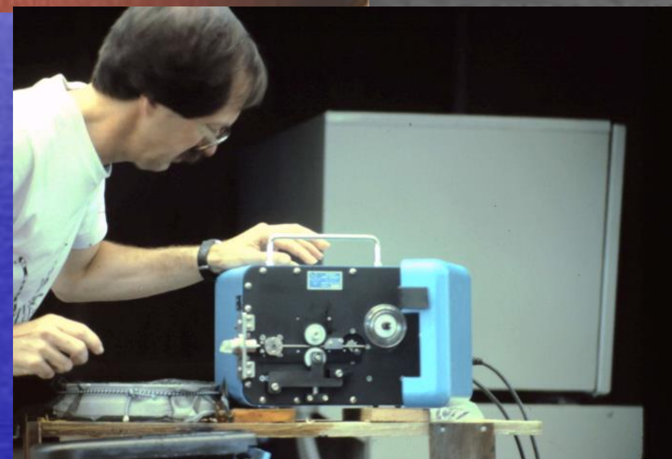
SURVIVAL IS HIGHLY DEPENDENT UPON RELEASE STRATEGIES

- Release Habitat
- Size-at-Release
- Release Season
- Acclimation
- Release Magnitude
- Interactive Effects

Tag Selection

Coded-wire Tag (CWT)

- Benign
- Easily and quickly applied
- Works well with small and large fish
- High retention, retained over lifetime of individual
- Cost effective, (~$0.1/Tag)
- High information content
- Not externally visible in most cases, must use detector
- Must sacrifice individual to remove tag for decoding
- Also used for double tagging studies: external tag retention, survival, growth



OAHU, HAWAII

Kaneohe Bay

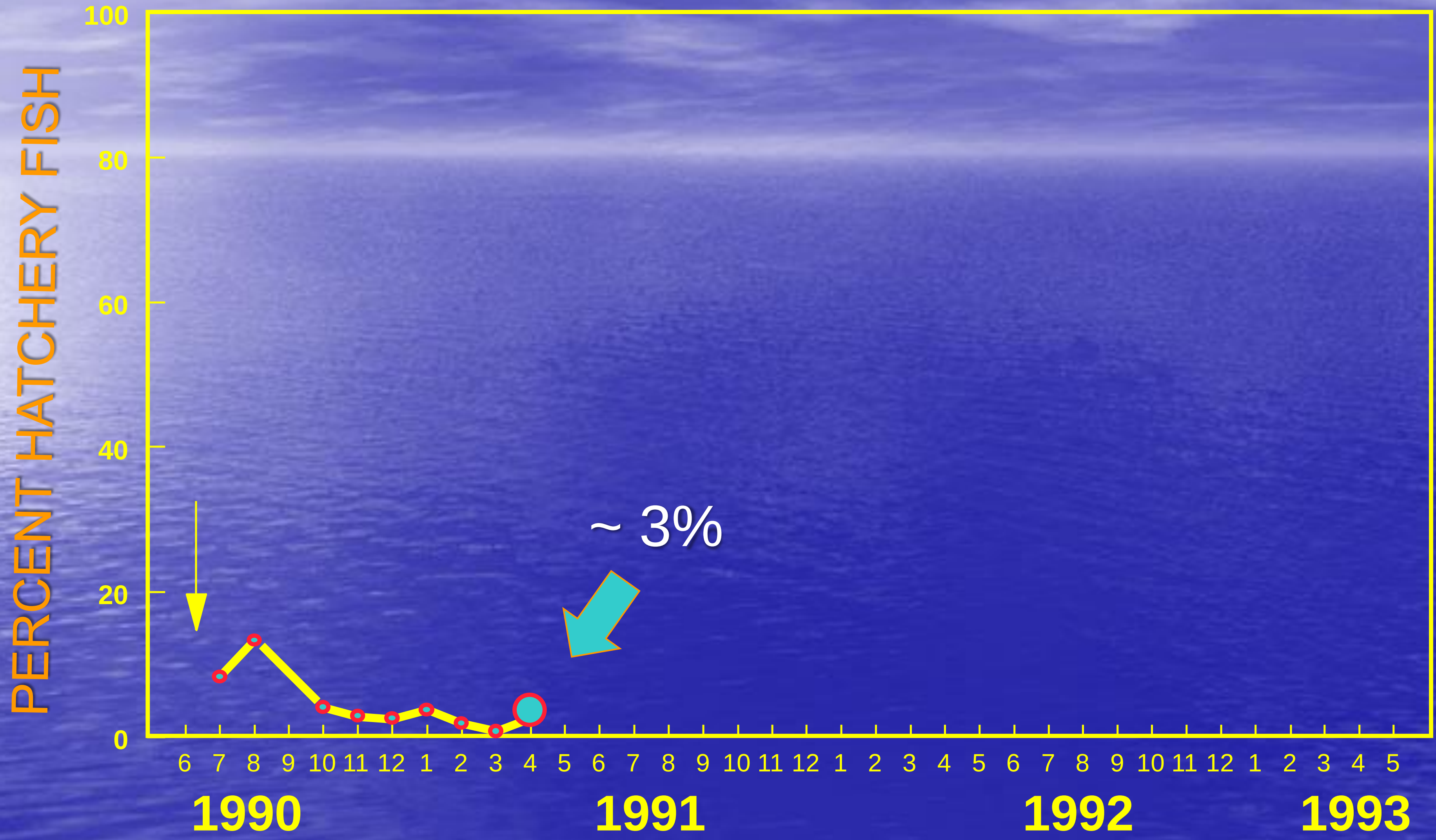
Effect of Release Habitat on striped mullet in Hawaii

- Kahaluu Steam (control site)
- Shoreline of Kaneohe Bay (treatment site)

	Number Released	Replicates (Lots)	Number Recaptured
Control Site	11676	2	20
Treatment Site	31146	3	0

Leber, K. M. 1995. Significance of fish size-at-release on enhancement of striped mullet fisheries in Hawaii. Journal World Aquaculture Society 26(2):143-153.

Survival and Recruitment



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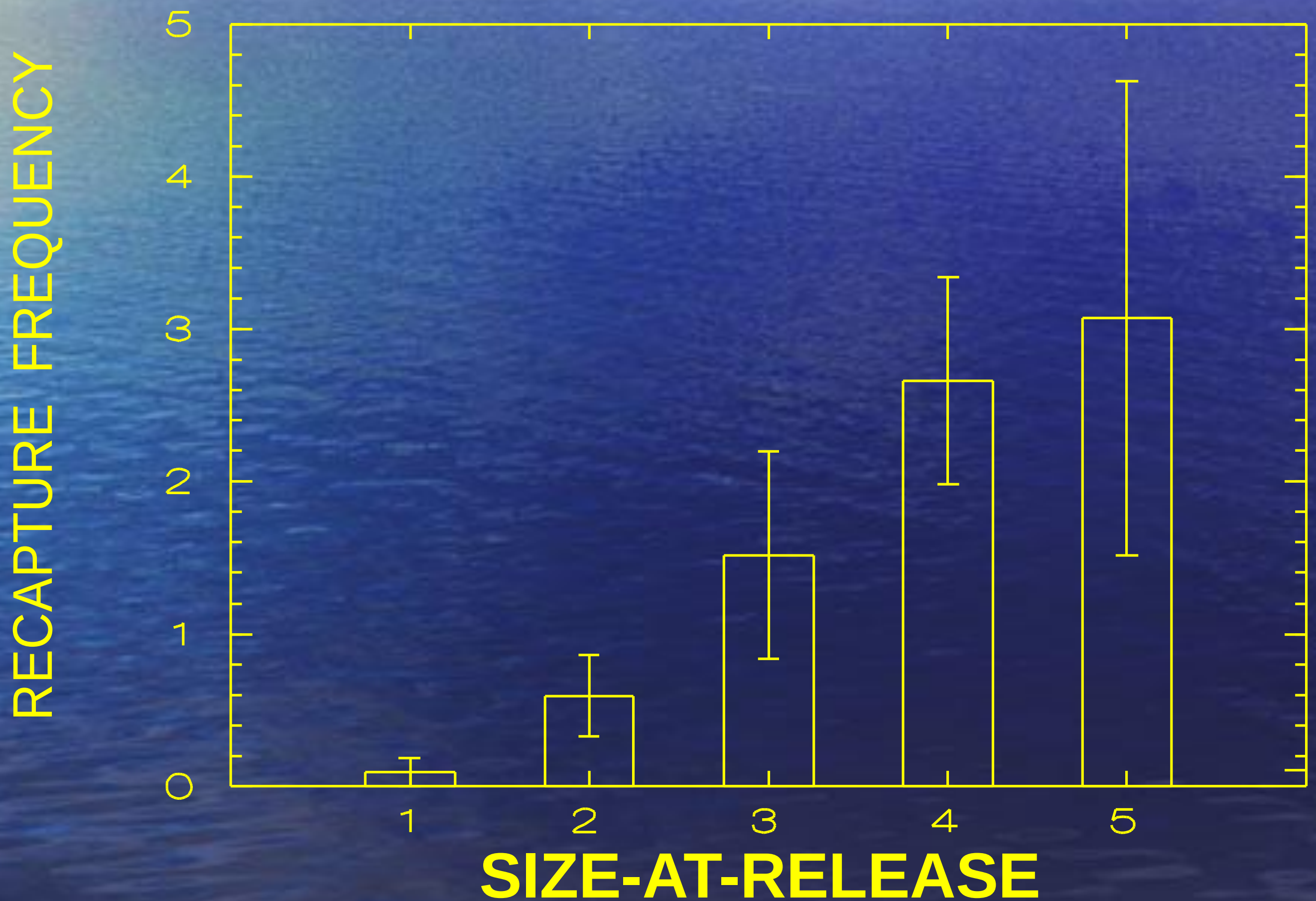
Rationale for Pilot Studies to Optimize Release Protocol

Size-at-Release Impact in Kaneohe Bay

RECAPTURES FOLLOWING SUMMER RELEASE



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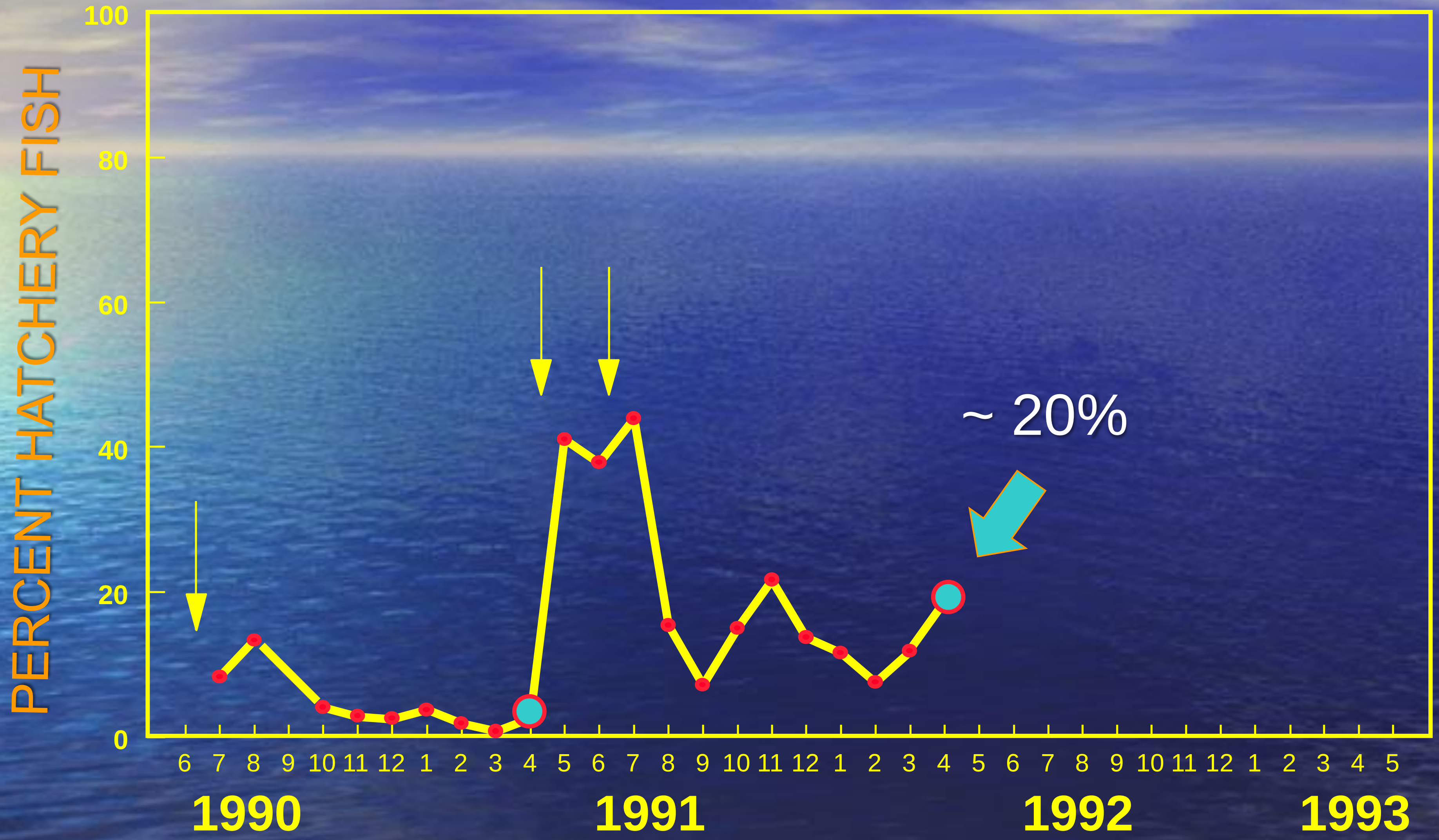
Gains in Survival and Recruitment



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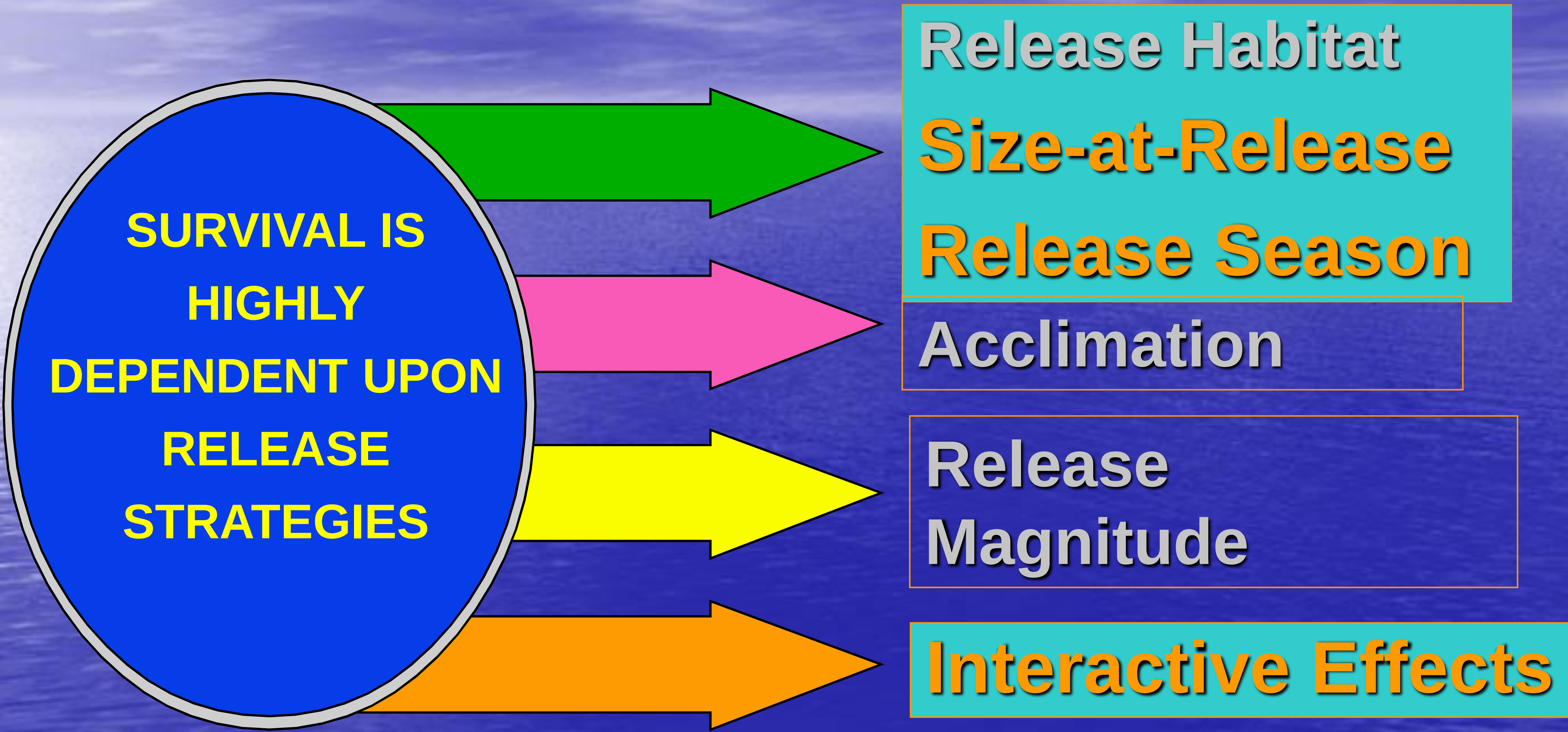
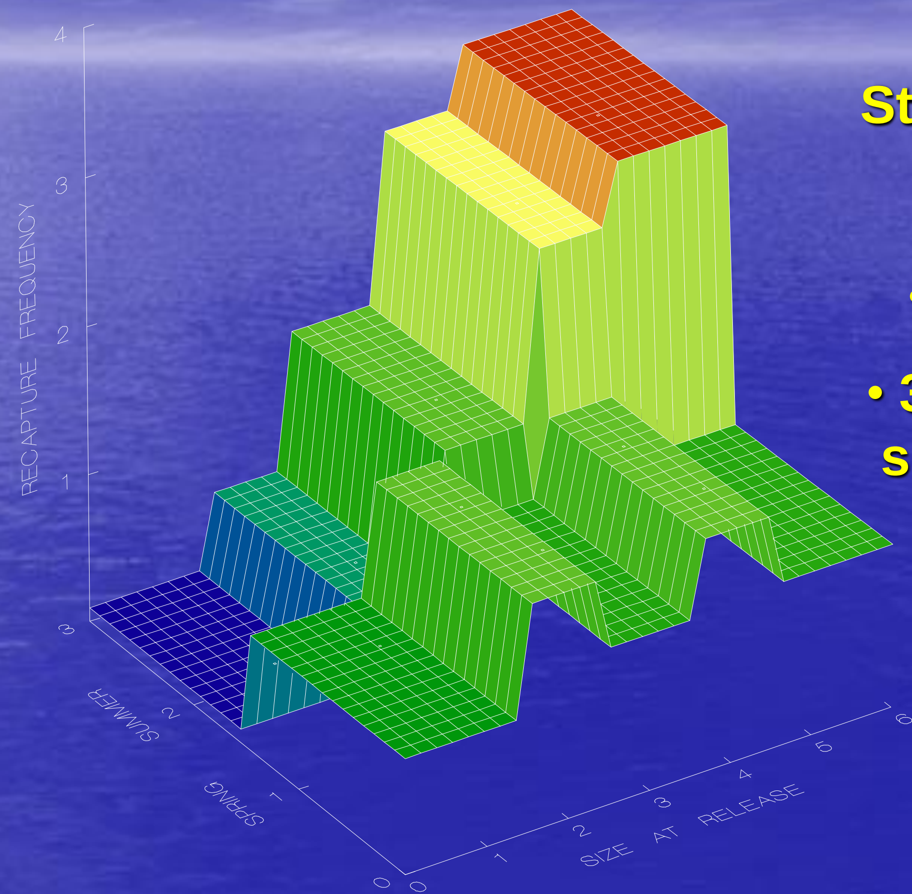


Release Season Interaction With Size-at-Release Effect



Striped Mullet in Hawaii

- **5 sizes released**
- **Spring vs Summer**
- **3 replicate releases in spring and in summer**

Leber, K. M., H. L. Blankenship, S. M. Arce, and N. P. Brennan. 1997. Influence of release season on size-dependent survival of cultured striped mullet, *Mugil cephalus*, in a Hawaiian estuary. Fishery Bulletin, 95(2):267-279.

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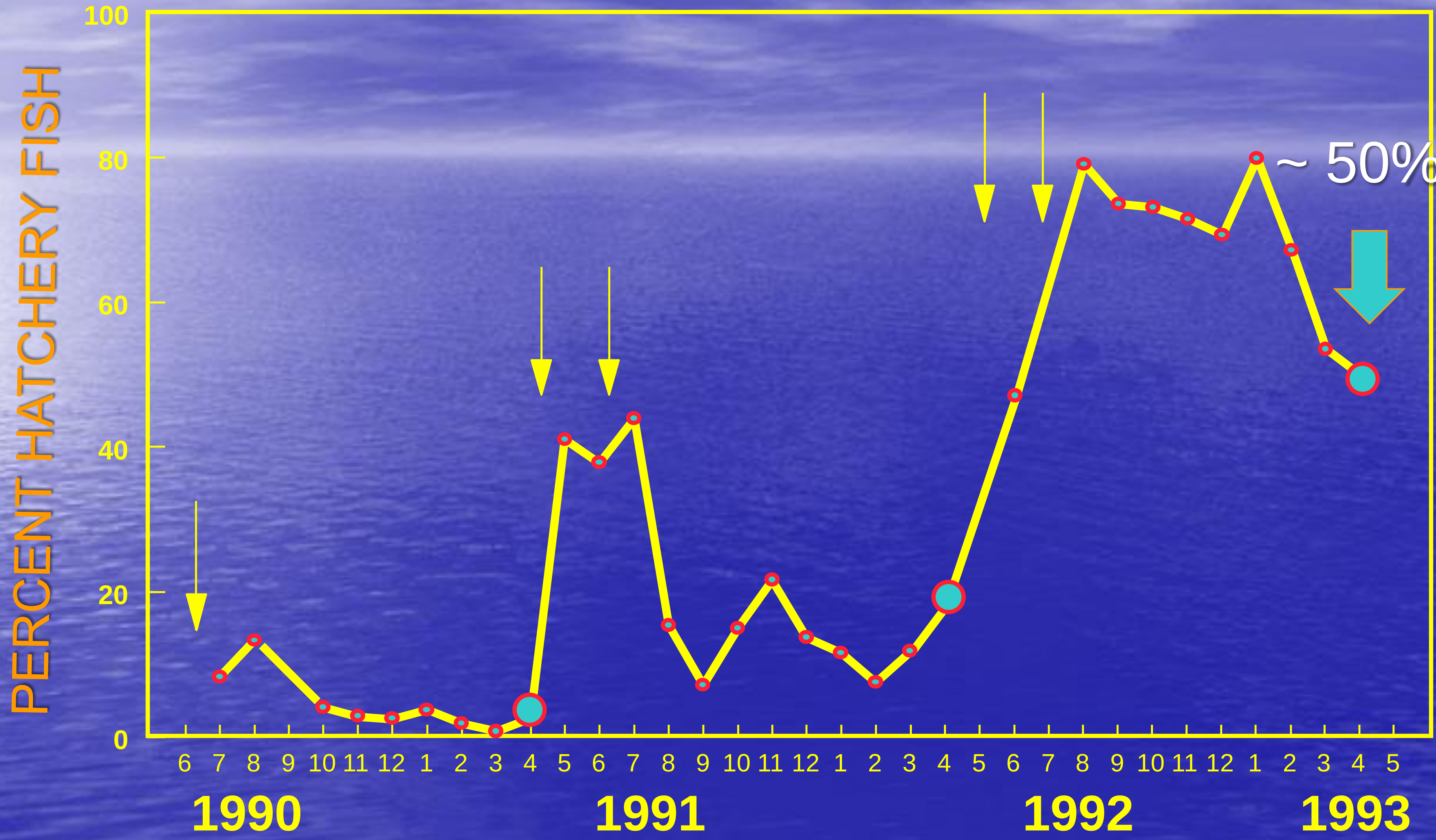

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Enhancement Cost Efficiency

- RELATIVE COST TO ENHANCE (RCE)
  - C.E. = PRODUCTION COST / NO. CAPTURED

$$= \frac{\text{NO. PRODUCED} \times \text{UNIT COST}}{\text{NO. RELEASED} \times \text{RECAP. FREQ}}$$

$$\text{RCE} = \frac{\text{UNIT COST}}{\text{RECAP. FREQ}}$$

- Choose release tactic that minimizes CE

Leber, Cantrell and Leung. 2005. Optimizing cost effectiveness of size-at-release in stock enhancement programs. N. Am. J. Fish. Mgmt. 25:1596-1608

Basic Cost Parameters: Fish Size-at-Release (SAR)

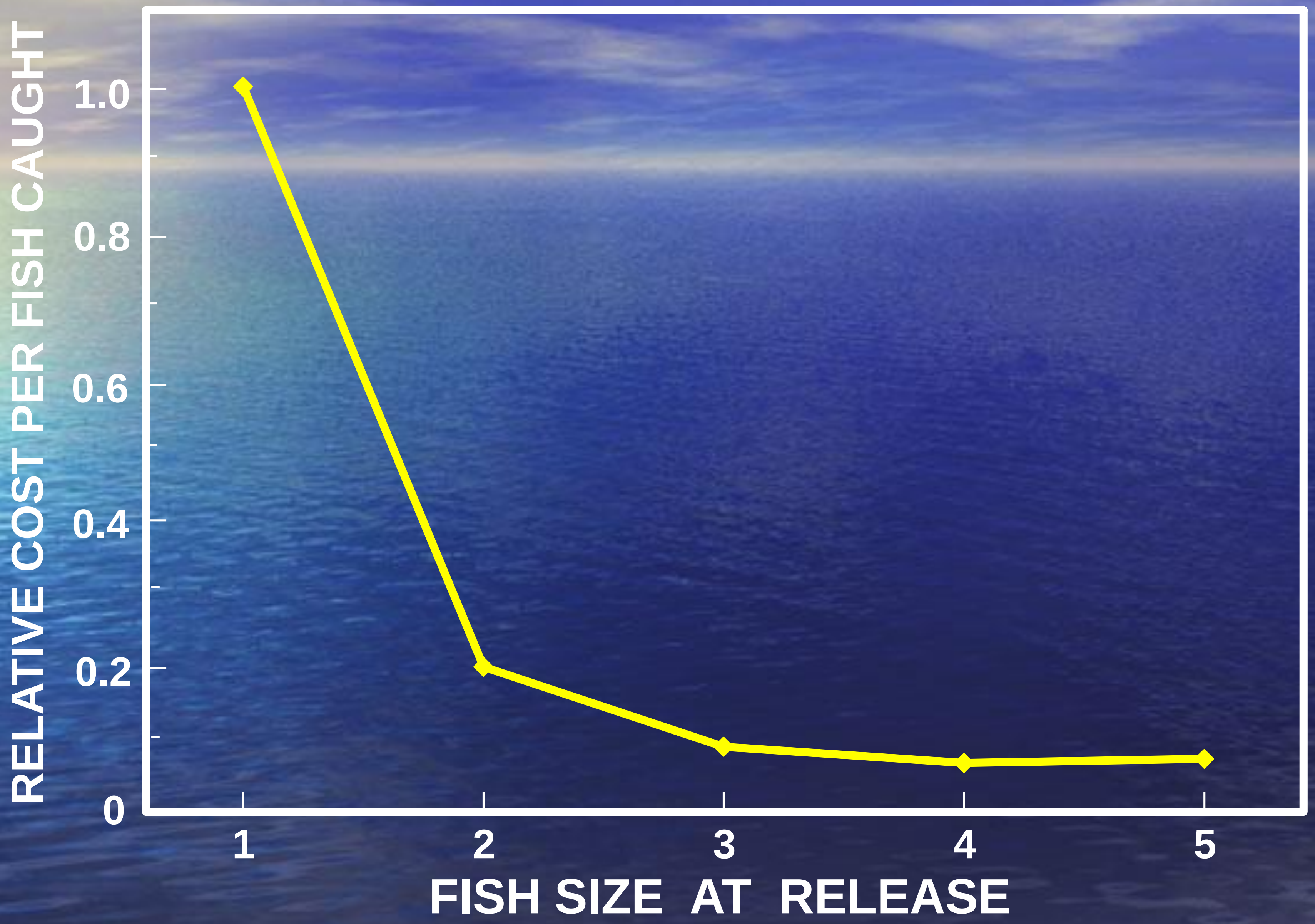
- Key Parameters: SAR based-production levels;-production costs;-fishery yields

SAR LEVEL

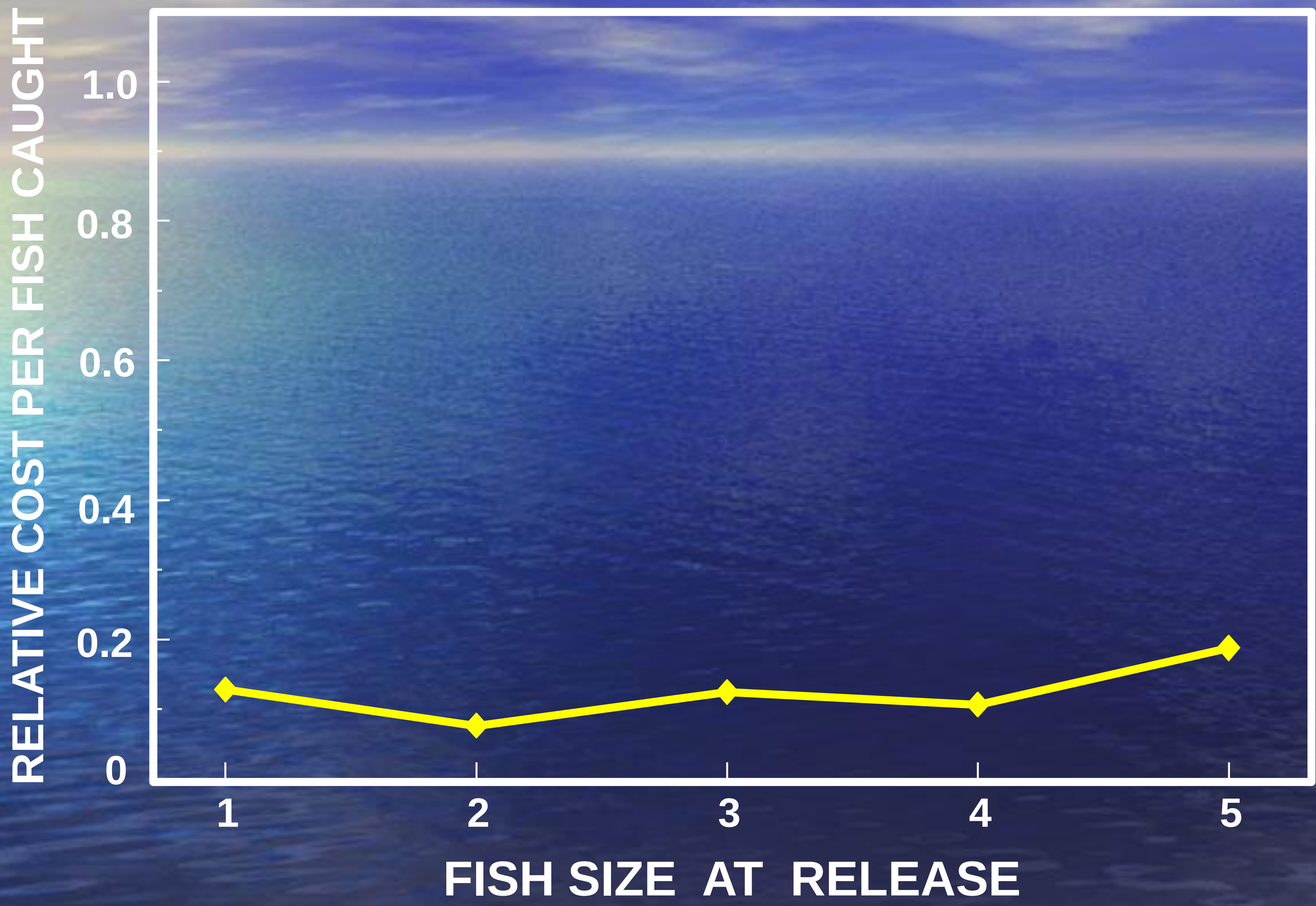
	45-60mm	60-70	70-85	85-110	110-130
#	127,680	120,690	117,936	109,164	103,706
Unit cost	$0.31	$0.37	$0.42	$0.54	$0.68
RF	.001	.006	.016	.027	.031
RCE	$310	$62	$26	$20	$22

Leber, Cantrell and Leung. 2005. Optimizing cost effectiveness of size-at-release in stock enhancement programs. N. Am. J. Fish. Mgmt. 25:1596-1608

RELATIVE COST (SUMMER RELEASES)



RELATIVE COST (SPRING RELEASES)



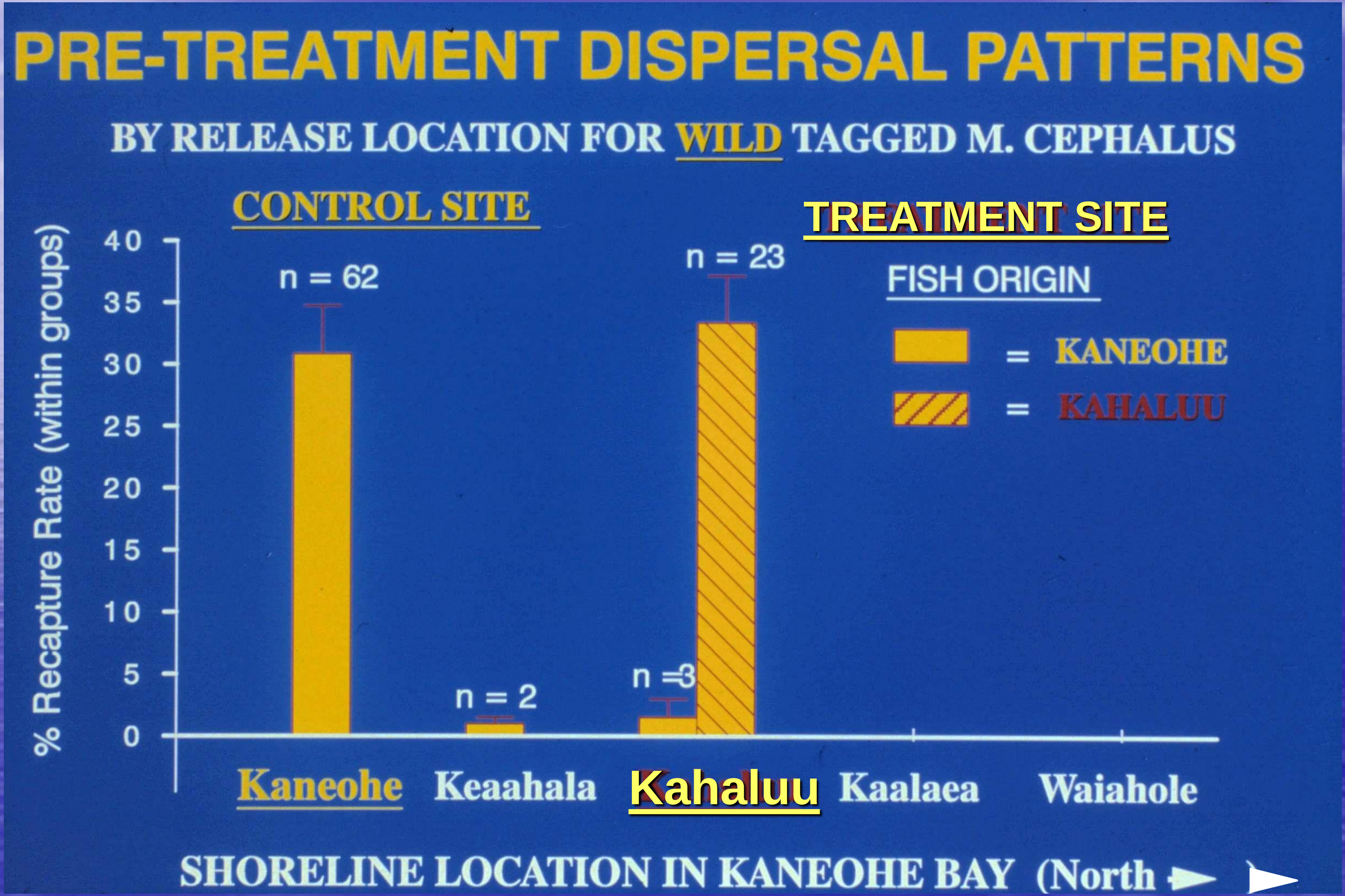
Hypothesis:

Marine Hatchery Releases Increase Fish Abundance

Predictions:

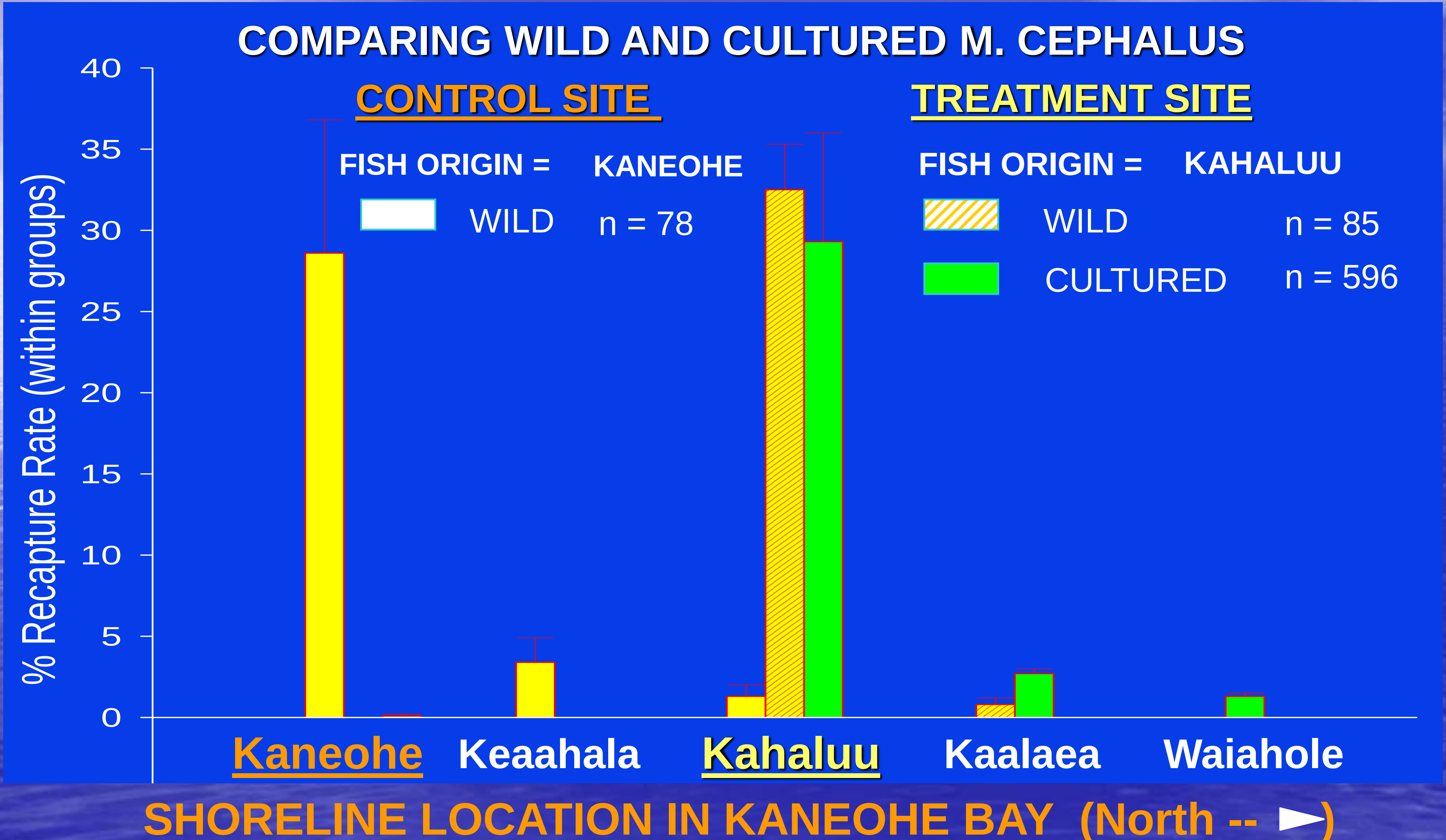
- **Cultured Marine Fish Survive & Grow in the Wild** ✓
- **Hatchery Releases Contribute to Fishery Landings** ✓
- **Hatchery Fish Do Not Displace Wild Stocks** ?

Dispersal From Release Site



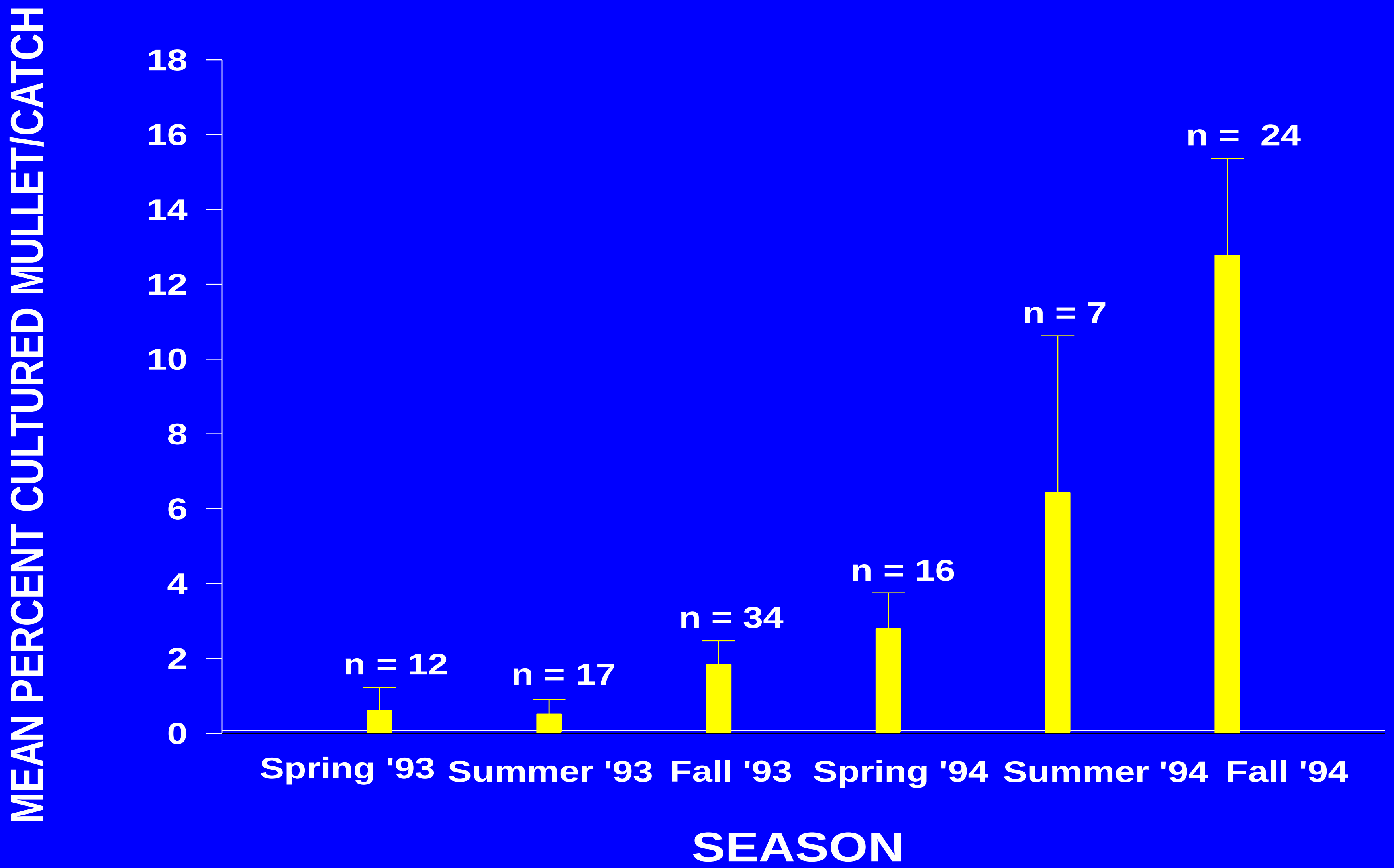
Leber, K.M, N.P. Brennan and S.M. Arce. 1995. Marine enhancement with striped mullet: are hatchery releases replenishing or depleting wild stocks? In *Uses and Effects of Cultured Fishes in Aquatic Ecosystems*. American Fisheries Society Symposium 15:367-387.

Dispersal From Release Site



Leber, K.M, N.P. Brennan and S.M. Arce. 1995. Marine enhancement with striped mullet: are hatchery releases replenishing or depleting wild stocks? In *Uses and Effects of Cultured Fishes in Aquatic Ecosystems*. American Fisheries Society Symposium 15:367-387.

PERCENT CONTRIBUTION OF CULTURED STRIPED MULLET TO KANEOHE BAY COMMERCIAL FISHERY



Leber, K.M and S.M. Arce. 1996. Stock enhancement in a commercial mullet, *Mugil cephalus L., fishery in Hawaii.* Fisheries Management and Ecology 3:261-278.

www.StockEnhancement.org

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Probing the Potential of Marine Stock Enhancement

The Science Consortium for Ocean Replenishment (SCORE) is developing responsible, effective, and scientifically-based marine stock enhancement & restocking technologies. The consortium is a multi-state US initiative to help boost recovery of depleted fisheries.

What is stock enhancement?
The fish and invertebrates that support coastal fisheries are among our Nation's most important natural resources. Sustaining these is much more challenging today than in the past. Stock enhancement entails releasing hatchery-reared juveniles into the wild to augment the natural supply of juveniles and help optimize fishery harvests.

Prior to the 1970s, the effectiveness of stocking marine organisms had not been examined. Around 1990, debate about the scientific basis for stocking hatchery-reared organisms stimulated Hatchery Reform in the US Pacific Northwest and also fostered the development of a 'responsible approach' to marine fisheries enhancement, which continues to see expanded adoption worldwide.

The need for a science-based and responsible approach is clear. The principles and techniques for managing stocking programs effectively are now available. Adoption of a Responsible Approach leads to clarification of the results of stocking organisms into the sea to help replenish or enhance recruitment-limited fish stocks. The

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Publications on Fisheries Enhancement Authored by SCORE Scientists

Responsible approach to stock enhancement

'Responsible Approach' Concept

Lorenzen, K., K. M. Leber and H. L. Blankenship. 2010. Responsible approach to marine stock enhancement: An update. Reviews in Fisheries Science 18(2):189-210. >>read now...

NEW Sass, G. G., and M. S. Allen, editors. 2014. Foundations of Fisheries Science. American Fisheries Society, Bethesda, Maryland. [The original 'Responsible Approach' (Blankenship & Leber, 1995) is reprinted here in entirety] Note: this book documents advancement of marine fisheries enhancement into the mainstream of fisheries science] >>read front matter now...

Blankenship, H. L. and K. M. Leber. 1995. A responsible approach to marine stock enhancement. In Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society Symposium 15:165-175. >>read now...

Short Synopsis of the 'Responsible Approach' Concept...

Application of the Responsible Approach

NEW Leber, K.M. 2013. Marine fisheries enhancement: Coming of age in the new millennium. pp. 1139-1157 *In:* Paul Christou et al. (eds). Sustainable Food Production. Springer Science, New York. (Originally published *In:* Robert A. Meyers (ed). 2012. *Encyclopedia of Sustainability Science and Technology*. Springer Science. 20 pages.)


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YOU!