# The Why, When and How of Assessing Impingement and Entrainment Impacts

California State Water Resources Control Board Workshop on: Regulation and Impact Assessment of Once-Through Cooling Systems of California Coastal Power Plants

John Steinbeck
Tenera Environmental
141 Suburban Rd., Suite A2
San Luis Obispo, CA 93401
805-541-0310
jsteinbeck@tenera.com

# Assessing Impingement and Entrainment (I&E) Impacts

- **Introduction**
  - Types of CWIS Impacts
  - What Is the Goal of These Studies?
  - Impingement Study Design
  - Why Focus on Entrainment?

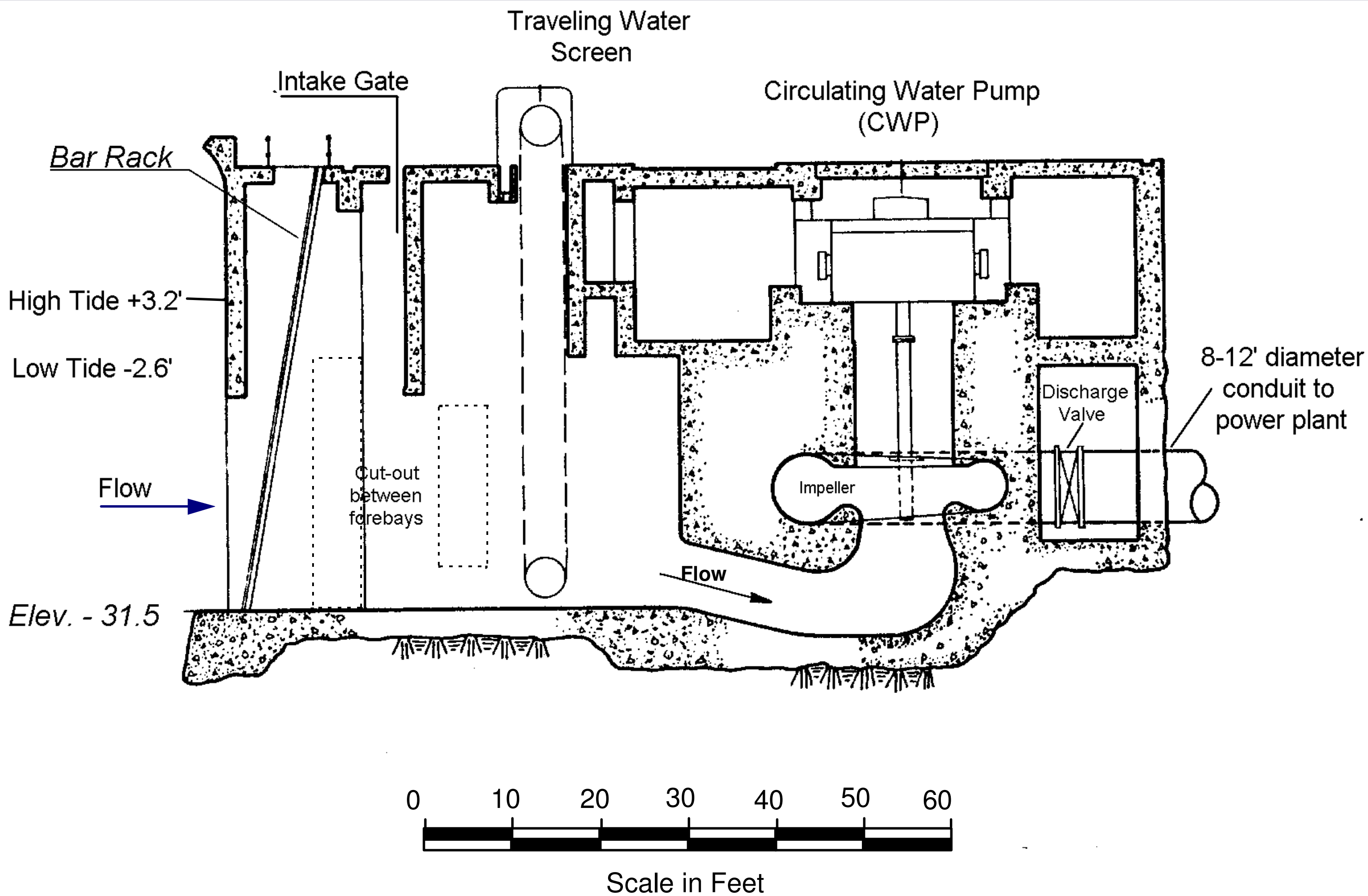
# Assessing I&E Impacts

- **Design Approach**
  - Entrainment Sampling Considerations
    - Where, What, How, Analysis
  - Source Water Sampling Considerations
  - Assessment Models
    - Other Necessary Data
    - Assumptions

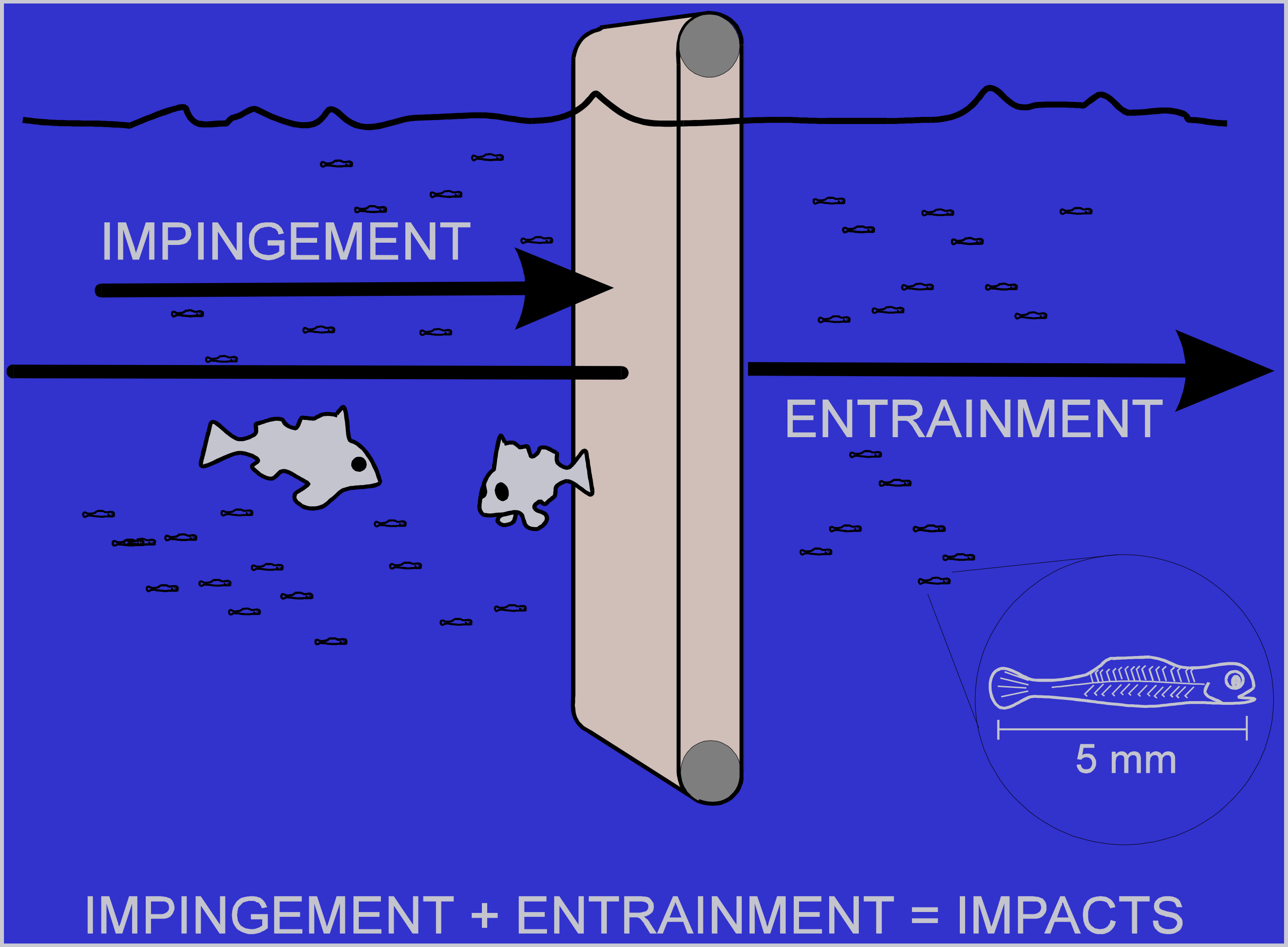
# Assessing I&E Impacts

- **Examples**
  – South Bay Power Plant – gobies
  – Diablo Canyon Power Plant – rockfishes
- **Interpretation**
- **Guidelines**
  – Study Design
  – Sampling and Sample Processing
  – Analysis
- **Conclusions**

# ‘Baseline’ Cooling Water Intake System



# CWIS Impacts



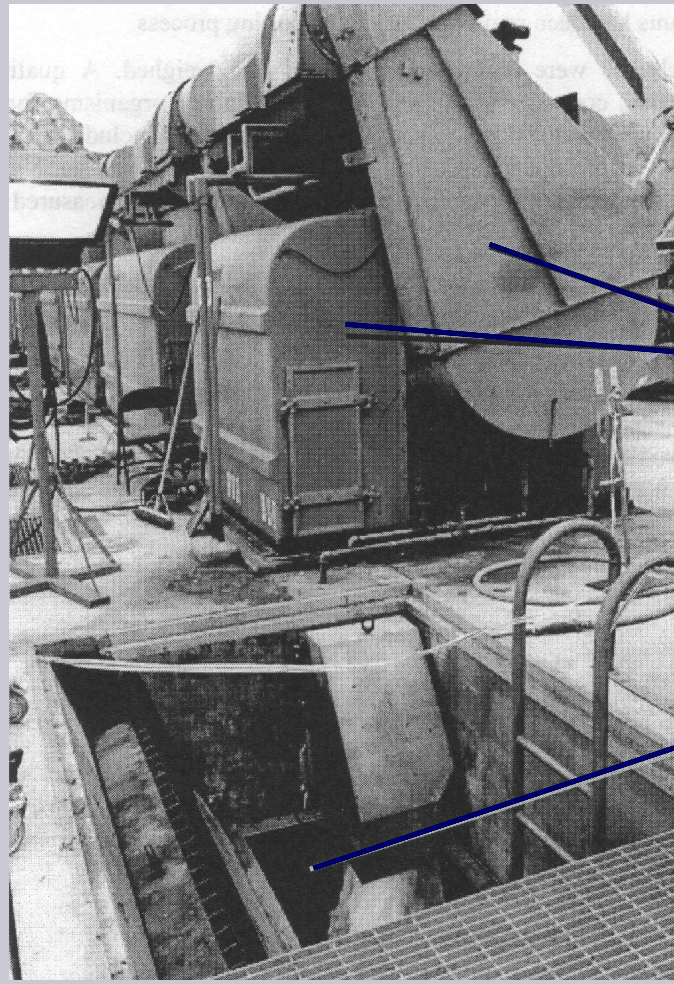
# Goals of I&E Studies

- Basic goal of these studies is estimation – not hypothesis testing
  - Estimate best, unbiased point estimate of population parameters – impingement, entrainment, source water numbers
  - Estimate measures of variance for confidence intervals
- Basic requirement is for characterizing IM&E and baseline
- Percentage based performance standards result in same benefit regardless of baseline

# Goals of I&E Studies

- Modeling effects on populations (demographic or conditional mortality) good for providing context for effects, but really only useful under new Rule for showing benefit of reductions or scaling restoration
- Impact Analysis - Comparison with source water, reference stations, etc. requires much more rigorous design and extensive data – BACI (see Steinbeck, et al. 2005. Ecol. Applications) – not part of new rule

# Impingement



# Impingement

- **Sampling**
  - Frequency – weekly or biweekly
  - Measure rate every 4 – 6 hours for 24 h
- **Estimating Impingement**
  - Quantify all fishes and shellfishes (crab, shrimp, etc.) and identify presence of other macro invertebrates
  - Rate = # or biomass / flow during sampling period
  - Average rate per 24 h period used to extrapolate over days between surveys based on actual, maximum, or estimated flow
  - Data over year added to heat treatment collections to estimate total annual impingement

# Impingement

**Annual Weight of Impinged Fish Based on Actual Flow (Note Table is based on representative facilities and does not include impingement during heat treatments).**

| Power Plant | County | Study Year | Maximum Intake Volume (million gal/day) | Type of intake | Estimated annual weight (lbs) impinged |
|---|---|---|---|---|---|
| Moss Landing | Monterey | 1979-1980 | 1,412 | shoreline | 10,000 |
| Morro Bay | San Luis Obispo | 1999-2000 | 670 | shoreline | 2,500 |
| Diablo Canyon | San Luis Obispo | 1985-1986 | 2,500 | shoreline | 1,600 |
| El Segundo | Los Angeles | 1999-2004 | 399 | offshore | 500 |
| Huntington Beach | Orange | 1979-2004 | 241[1] | offshore | 3,500 |
| Harbor | Los Angeles | 1978-1979 | 108[2] | shoreline | 6,200 |
| Haynes | Los Angeles | 1978-1979 | 968[3] | shoreline | 3,000 |
| Scattergood | Los Angeles | 1978-1979 | 495[4] | offshore | 6,940 |
| Encina | San Diego | 2002-2003 | 857 | shoreline | 5,000[5]–8,000[6] |
| South Bay | San Diego | 2002-2003 | 601 | shoreline | 1,200 |

[1] average flow during the studied years
[2] current maximum flow. Average daily flow during impingement study was 241 mgd
[3] current maximum flow. Average capacity factor during study was 46%
[4] current maximum flow. Average capacity factor during study was 58%
[5] weight based on actual annual cooling water flow during the study
[6] weight based on maximum annual cooling water flow

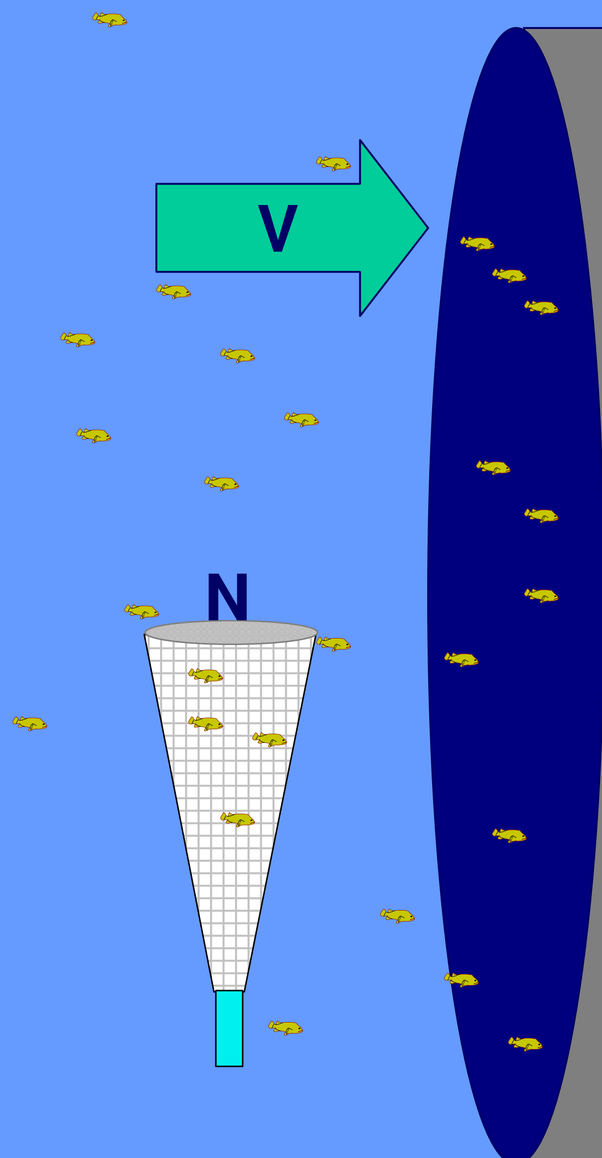
# Impingement

- Site-specific results based on location, intake design, not just flow
  - Open ocean location, ex. Diablo Canyon, probably low because of low intake velocities and strong swimming ability of the fishes out on the open exposed coast
  - Plants in more protected harbors and bays such generally higher
  - Offshore intakes fitted with velocity caps also seem effective at reducing impingement
- Generally not considered a large problem at California plants, with exception of SONGS

# Why Focus on Entrainment?

- Much more difficult to sample and estimate effects
- Possibly greater potential for impacts due to large CWIS volumes at some facilities
- Unlike impingement, site-specific factors (plant and source water) affect study design
- Site-specific factors also affect ability to interpret results

# Entrainment

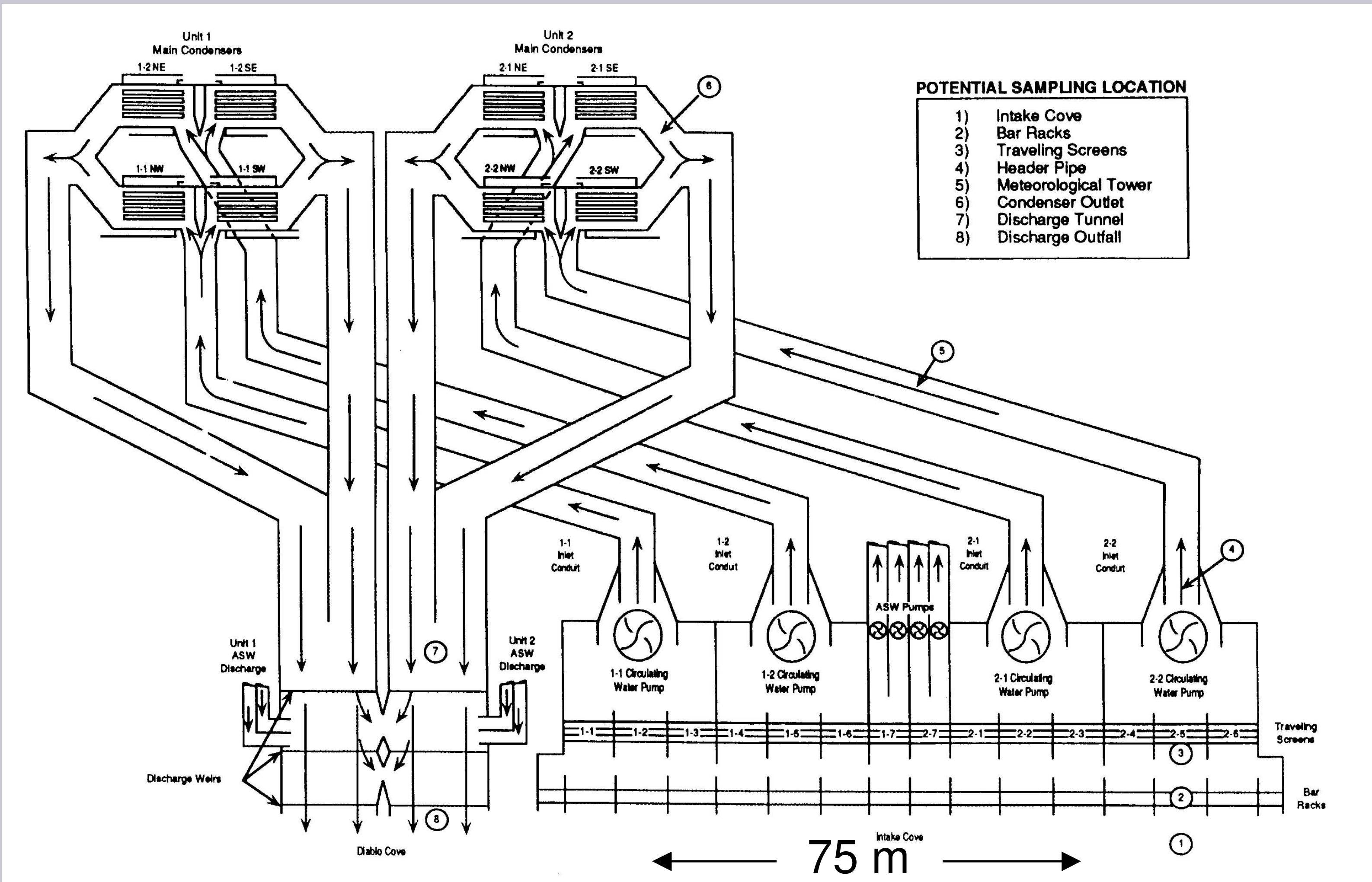



1. Calculate volume of cooling water entering the plant (V)
2. Measure concentration of larvae (number per volume) that are entrained (N)
3. *Assume no survival of larvae through the plant*
4. Entrainment = N x V

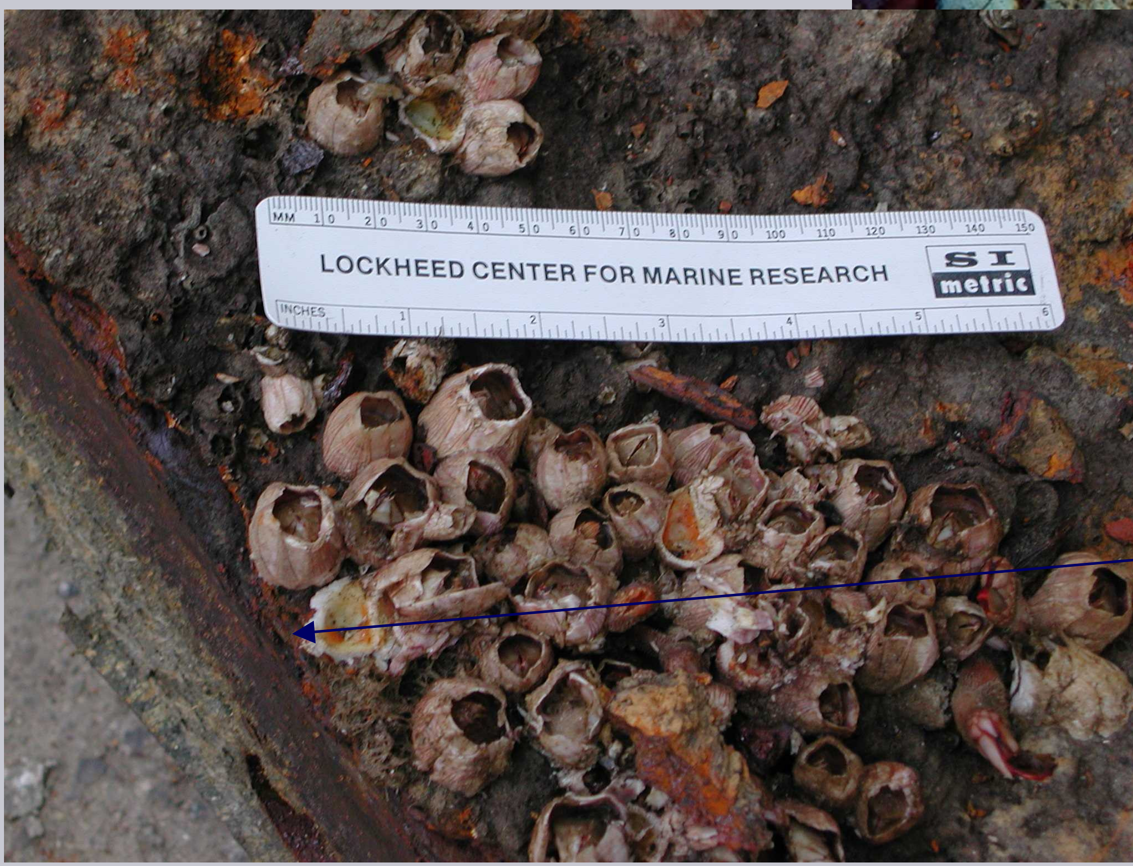
# Entrainment

- Where to get a representative sample?
- What to sample?
- Sample processing – resources, taxonomy
- How to assess results?

# Entrainment Sampling Location



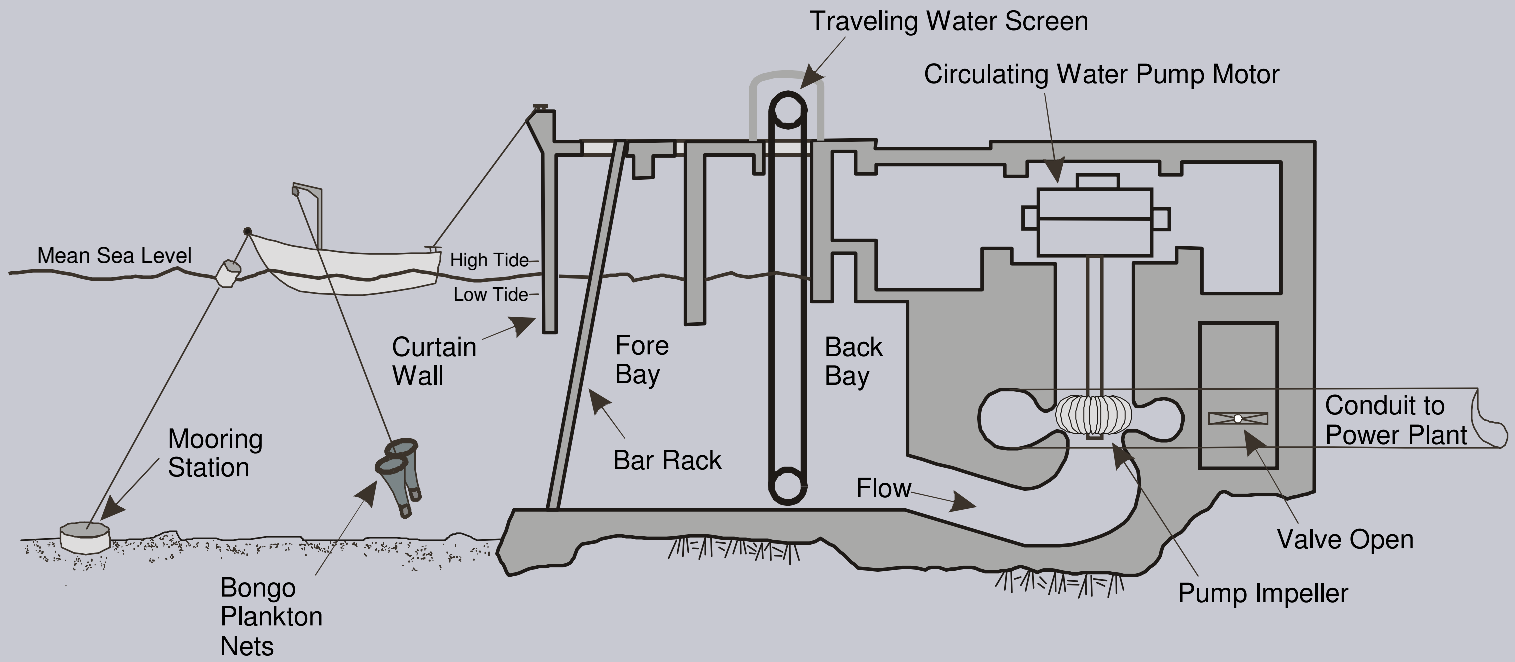
# Entrainment Sampling Location




bar racks

conduit walls

# Entrainment Sampling Location

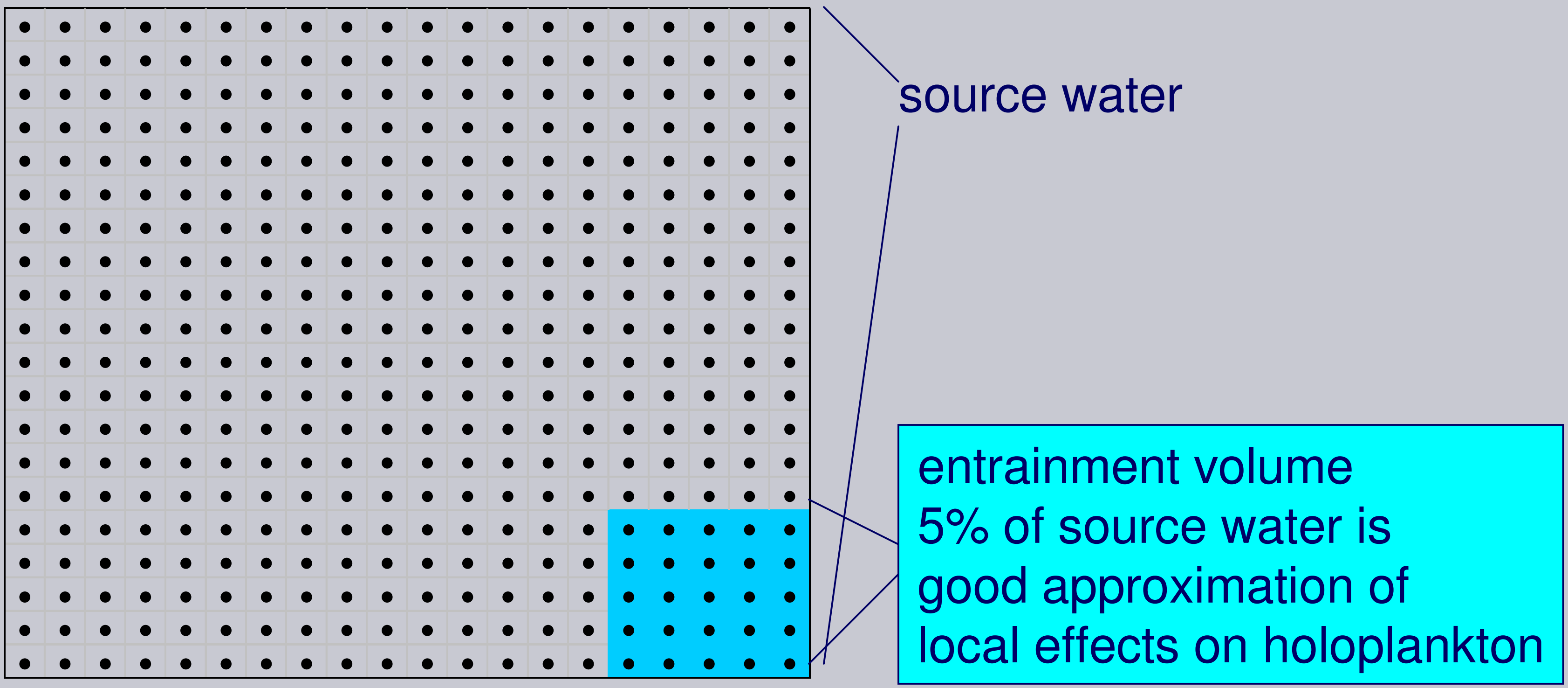


# What to Sample?

- New 316(b) Phase II Rule requires characterization of fish and shellfish
  - characterization vs. quantification
- What is a shellfish?
  - holoplankton vs. meroplankton
  - holoplankton may be distributed over large areas of ocean, have short generation times (days), and may be capable of reproducing as long as environmental conditions are favorable
  - meroplankton (larval fish and invertebrates) have limited distributions as adults along narrow coastal shelf, and may have limited spawning periods

# What to Sample?

- Volumetric estimates of effects on holoplankton (phyto- and zoo-plankton)

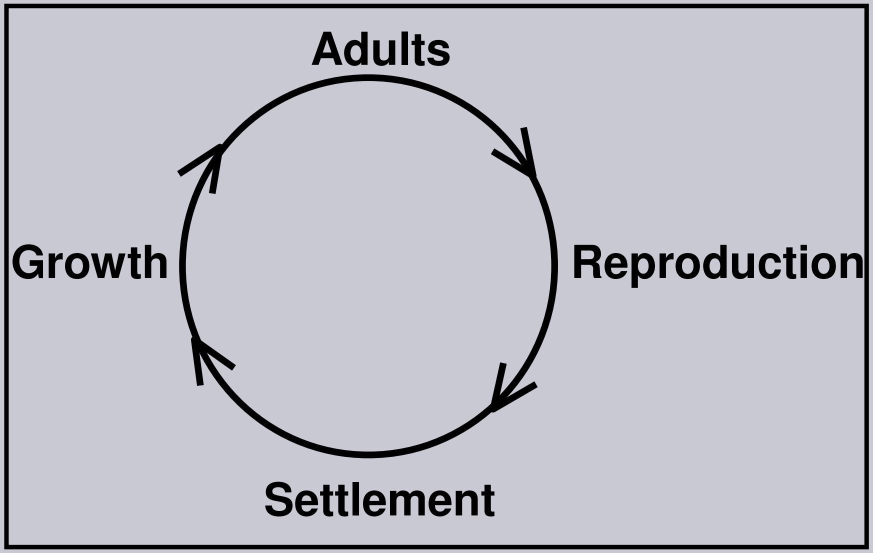


# What to Sample?

## Susceptible to larval entrainment?

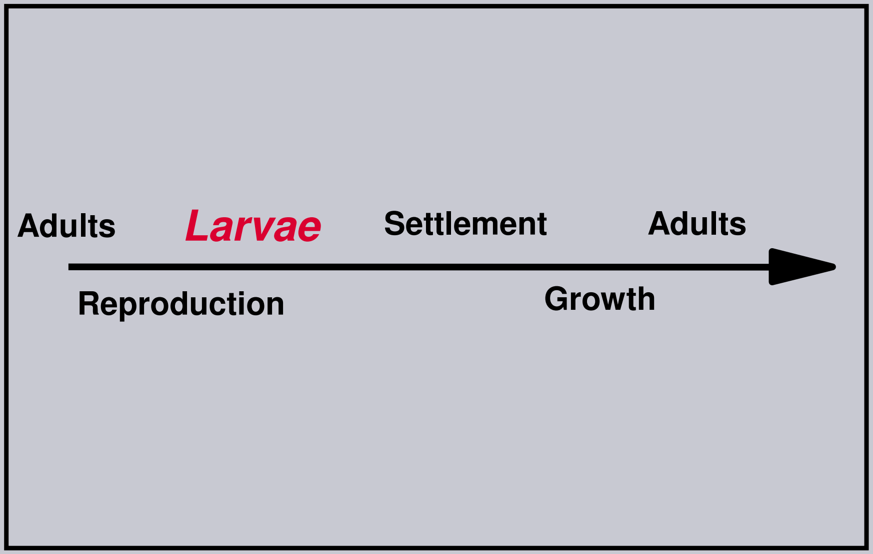
**NO**

Closed System (no larval phase)




**YES**

Open System (have a larval phase)

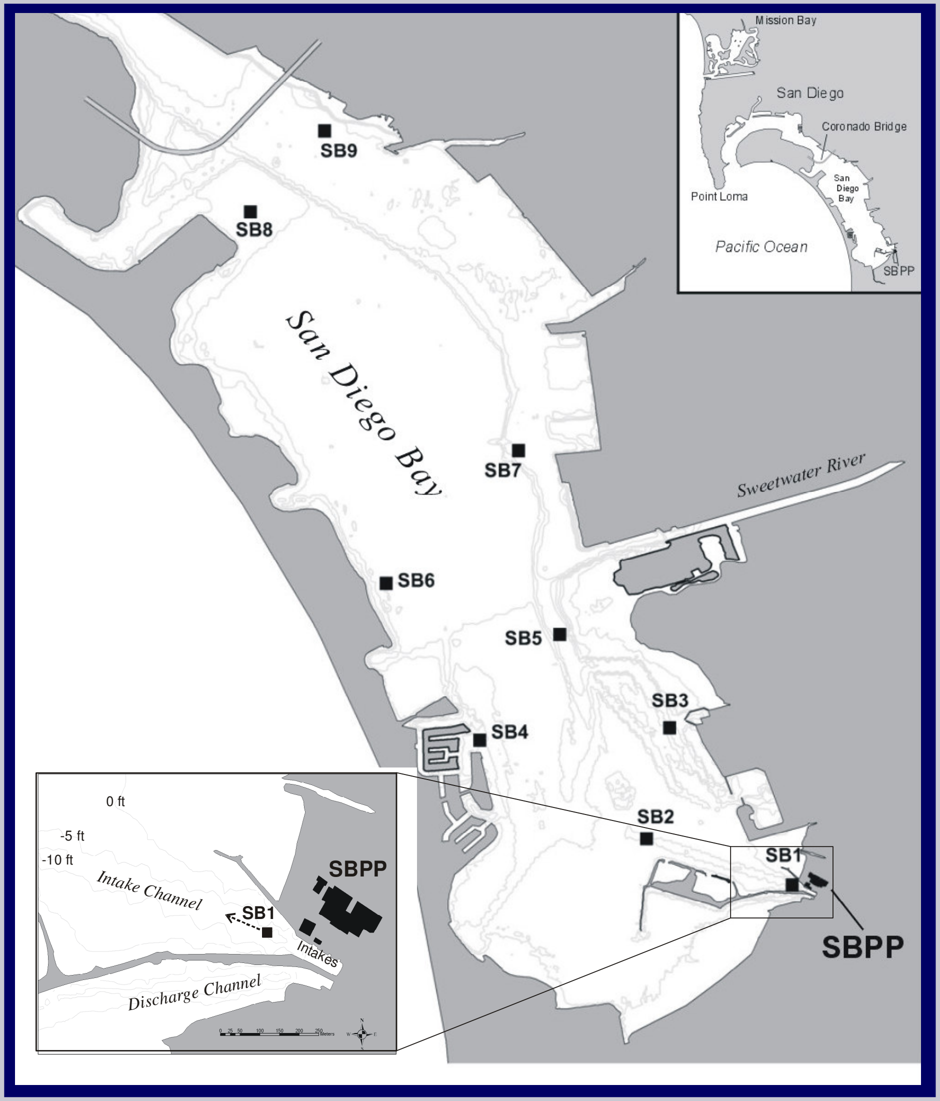



Surf Perch
Sharks
Rays

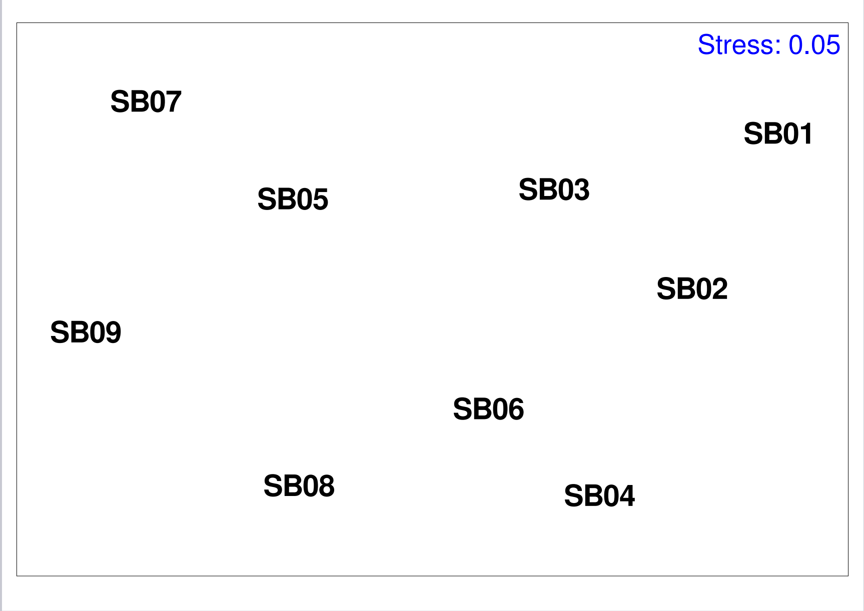
Gobies
Blennies
Sculpins

Herring
Clams
Crabs

# What to Sample?

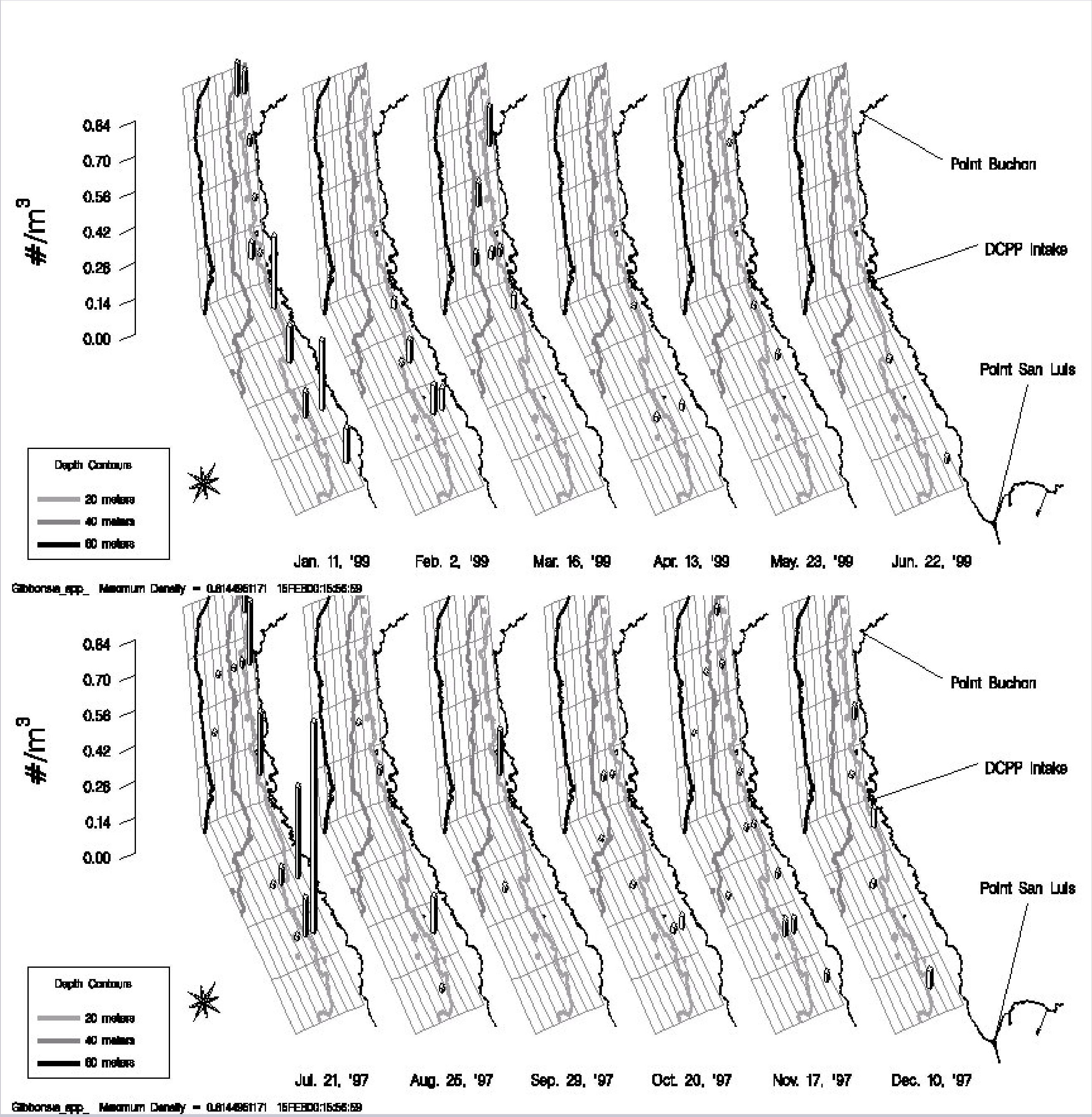



- Distribution of fish larvae may be closely associated with adult habitats – DCPP and SBPP
- Close to volumetric in other habitats - HBPP



# What to Sample?

larval kelpfish distribution during DCPP study



# What to Sample?

- **Fish Eggs**
  - Level of taxonomy doesn't correspond to level for larvae – quantitative use limited
  - Easy to account for in assessment models – add egg duration to ETM larval duration (assumes equal proportional entrainment for eggs and larvae)
  - Qualitative assessment accounted for by counting fish eggs from only entrainment samples - still results in lots of extra work that doesn't add equal amount of information

# Entrainment
## Sample Processing

- A 20-30 $m^3$ sample can take upwards of 40 h to process for larval fish, invertebrates, and fish eggs
- From all DCPP sampling - 150,000 larval fishes, 350,000 larval crabs identified

# Entrainment Sampling

- 335 vs 500 micron mesh
- Frequency – weekly or biweekly over 24h period every 4-6 h as close to intake as practical
- Duration – One year in absence of significant oceanographic events
  - PE estimates used in ETM should be independent of changes in larval abundance allowing less frequent source water collections (monthly)
- All subject to local conditions, species present (ex. Potrero)

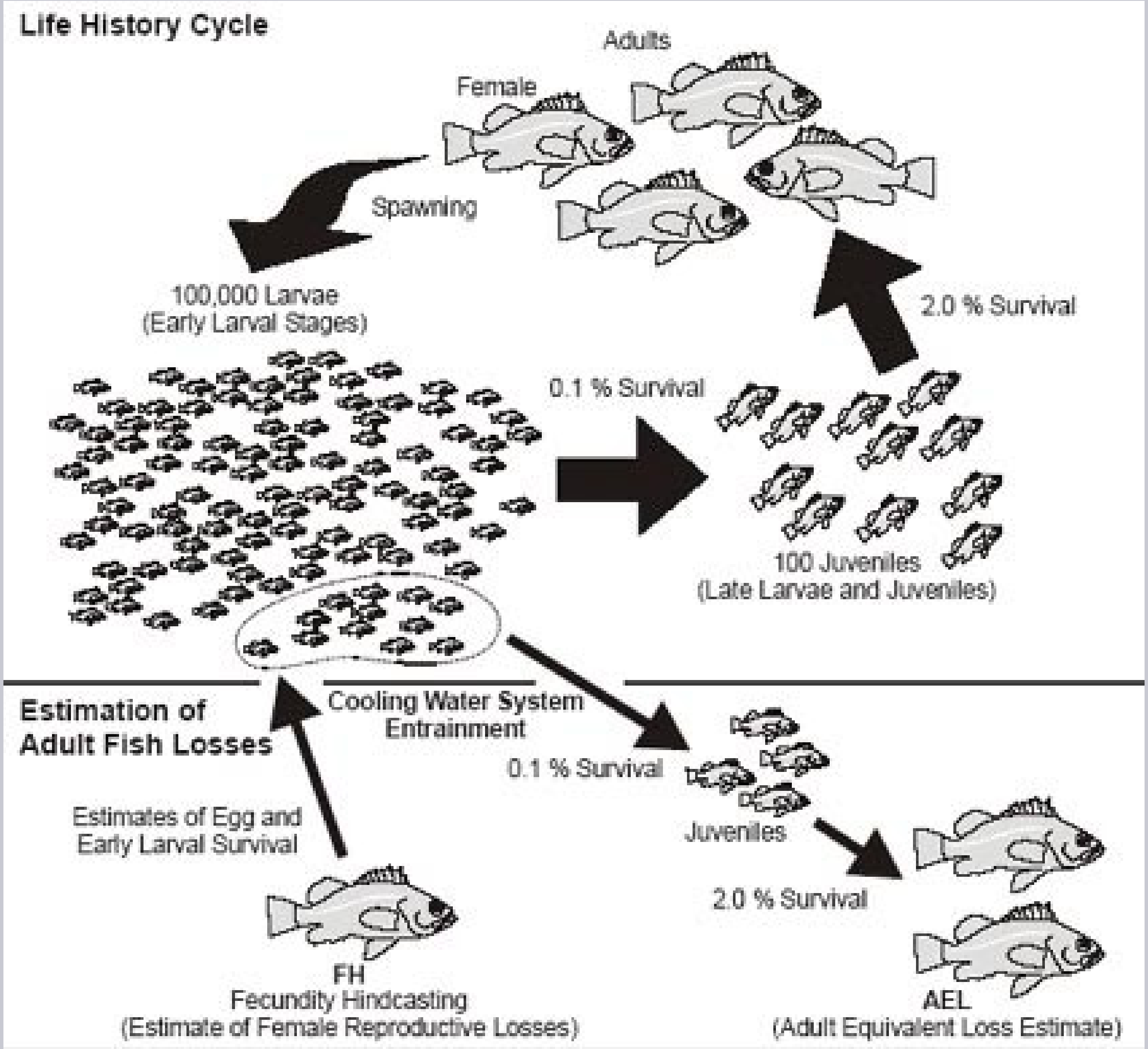
# **Entrainment**
# Assessment Models

- **Demographic Models** – useful in cost benefit
  - Adult Equivalent Loss (AEL)
  - Fecundity Hindcasting (FH)
  - Production Foregone
- **Conditional Mortality Models** – useful in scaling restoration
  - Empirical Transport Model (ETM)

# Entrainment

## Demographic Models

- fecundity
- age at maturity
- longevity
- survival data – eggs, larvae, other stages



# Entrainment
## Assessment Model Data

Demographic Models

- AEL – larval, juvenile, adult survival
- FH – fecundity, age at maturity, egg and larval survival

All of these usually drawn from literature – not site-specific, unknown what environmental, compensatory, depensatory, or other factors operating

# **Entrainment** Demographic Models

<u>Advantages/Disadvantages</u>

- Expresses losses as adults
- Requires life history information – not available for many taxa
- Requires adult stock data for interpretation
- Provides estimate for single year that may not be representative

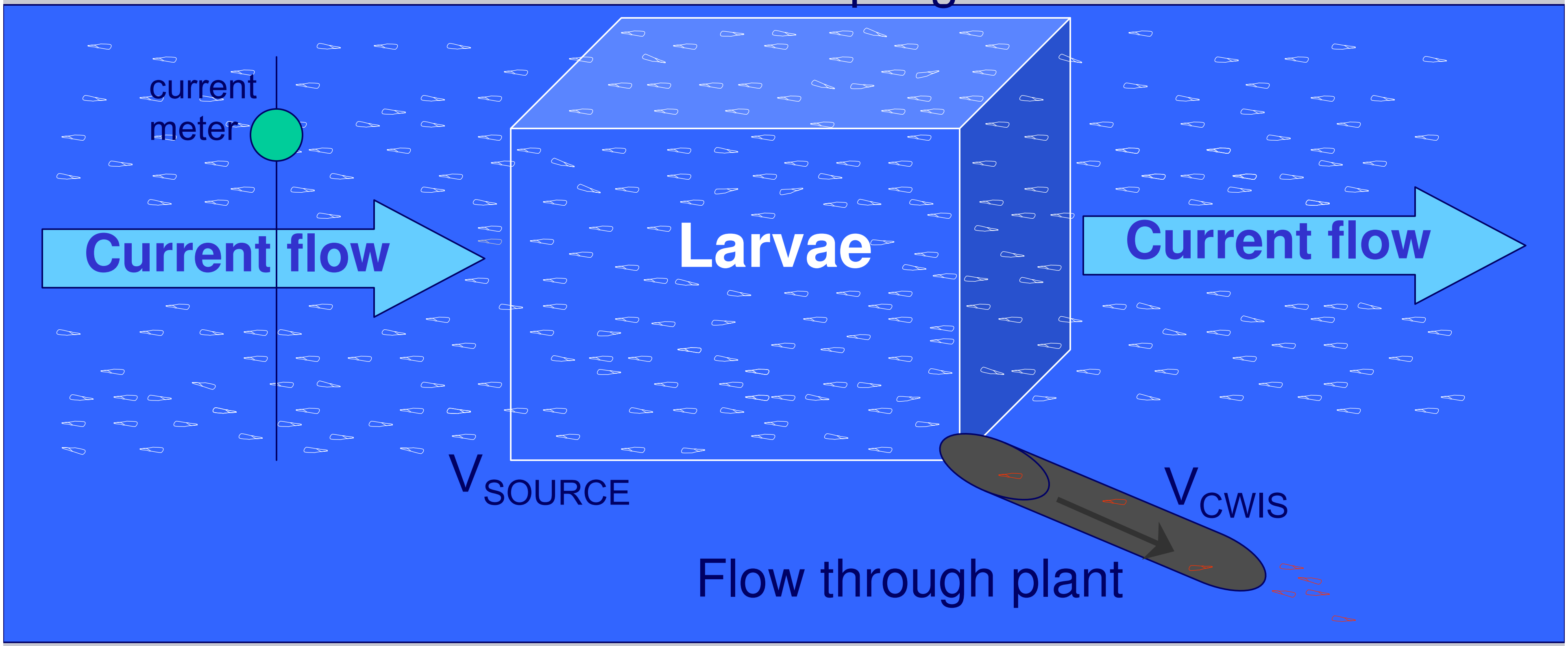
<u>Assumptions</u>

- Age-specific life history data are constant for the population
- Values are representative for the time and location of the study

# Entrainment

## Conceptualization of *ETM*

Nearshore Sampling Area




Conditional mortality due to entrainment = $\dfrac{\rho_{Entrainment} \bullet V_{CWIS}}{\rho_{SourceWater} \bullet V_{SOURCE}}$

# Empirical Transport Model

- Only life history information is larval growth rate to estimate duration

$$P_M = 1 - \sum_{i=1}^{n} f_i (1 - PE \bullet P_S)^{days}$$

- $P_s$ = ratio of area, volume, or number sampled to the larger population of inference – proportion of parental stock

# **Entrainment**
# ETM Model

Advantages/Disadvantages

- Expresses losses as larvae – the entity sampled
- Requires an estimate of larval stock - sampling
- Does not require life history information – except larval growth rate also required for demographic models
- Scaling results to population level may be difficult

Assumptions

- Field and entrainment sampling are representative
- Estimates constant within sampling period

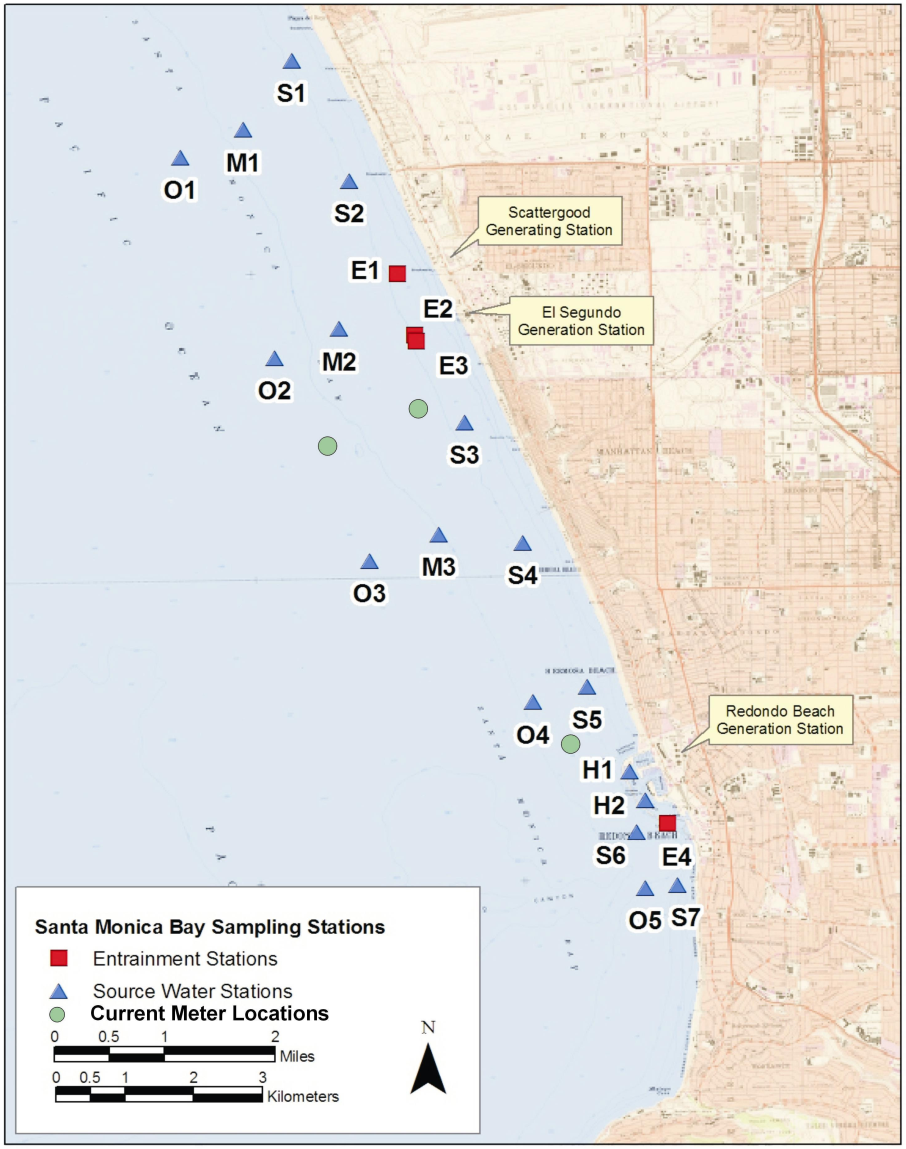
# Source Water Sampling

- Representative of range of habitats and species potentially affected by entrainment – listed spp., unique habitats
- For ETM, estimating daily proportional entrainment (PE) – area potentially subject to entrainment due to current or tidal flow
  - In open coast can be estimated using current data
  - In tidal estuary may encompass entire area
- Biweekly or monthly at same diel frequency as entrainment – depends on species present and conditions. Monthly in open coastal environments where PE = volumetric ratio.

# Source Water Sampling

## Santa Monica Bay

Cooperation among AES, NRG, and LADWP have resulted in design for Santa Monica Bay that is the most comprehensive cooling water system assessment since DCPP - 21 stations and 3 current meters



# Source Water Sampling
## Intake Hydraulic Zone of Influence (HZI)

- SW sampling designed to estimate spatial scale of entrainment effects that extend well beyond the HZI
- Focus on HZI could lead to biased sampling
  - Habitats outside HZI not sampled although they contribute larvae to entrainment
  - Ignores dynamics of source water
  - Ignores the time of larval exposure
  - Entrainment sampling done within HZI

# Entrainment
## Assessment Model Data

- ETM and Demographic Models both require data on age of larvae
- Estimated using larval growth rate from literature and lengths of larvae measured from entrainment

# Entrainment
## Other Data

- Power plant cooling water flow (actual, design, or planned) for entrainment estimates
- Bathymetry for source water volume estimates
- Current data for coastal source water
- Other hydrodynamic data for determining source water in estuarine systems

# **Entrainment**
# Defining Source Water Population and Example Results

- Closed estuarine system – South Bay Power Plant, San Diego, CA
- Open coastal system – Diablo Canyon Power Plant, Avila Beach, CA

# Closed Estuarine System

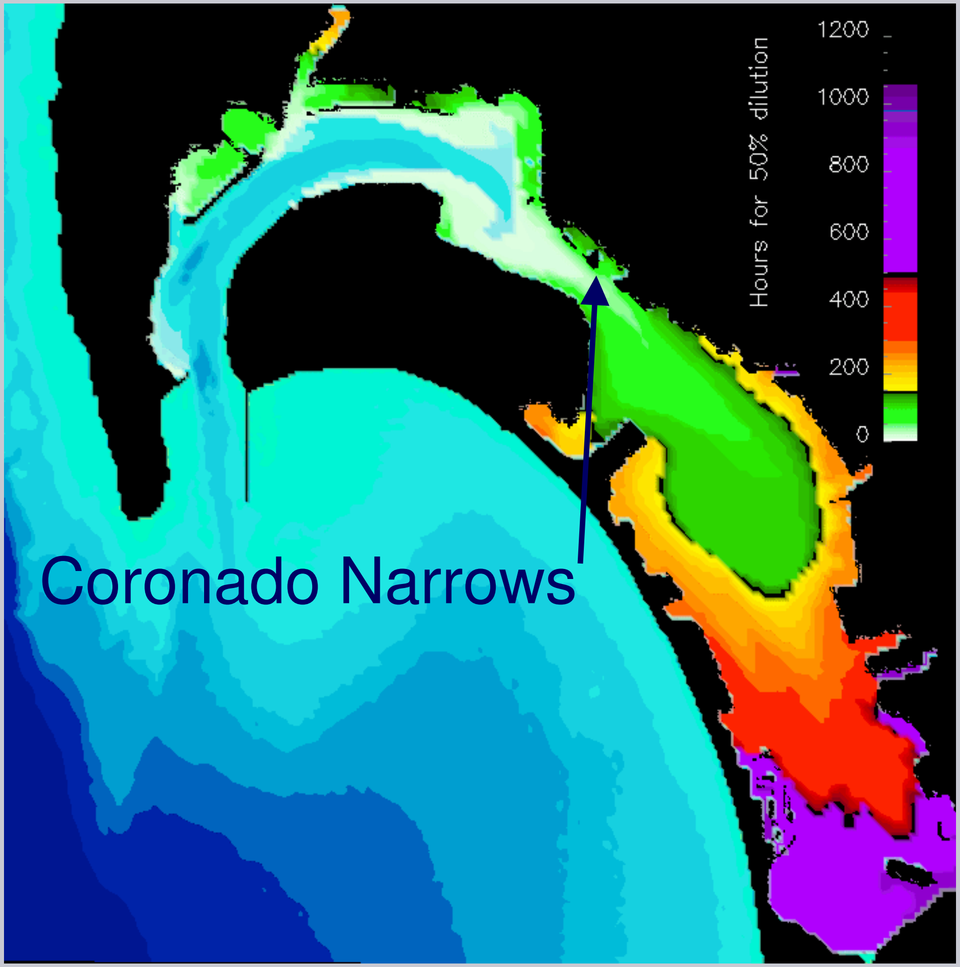
## South Bay Power Plant

# Closed Estuarine System
## South Bay Power Plant

- $P_s$ = 1.0 means that entire source water sampled
- Justify source water area, volume, and sampling

# Closed Estuarine System

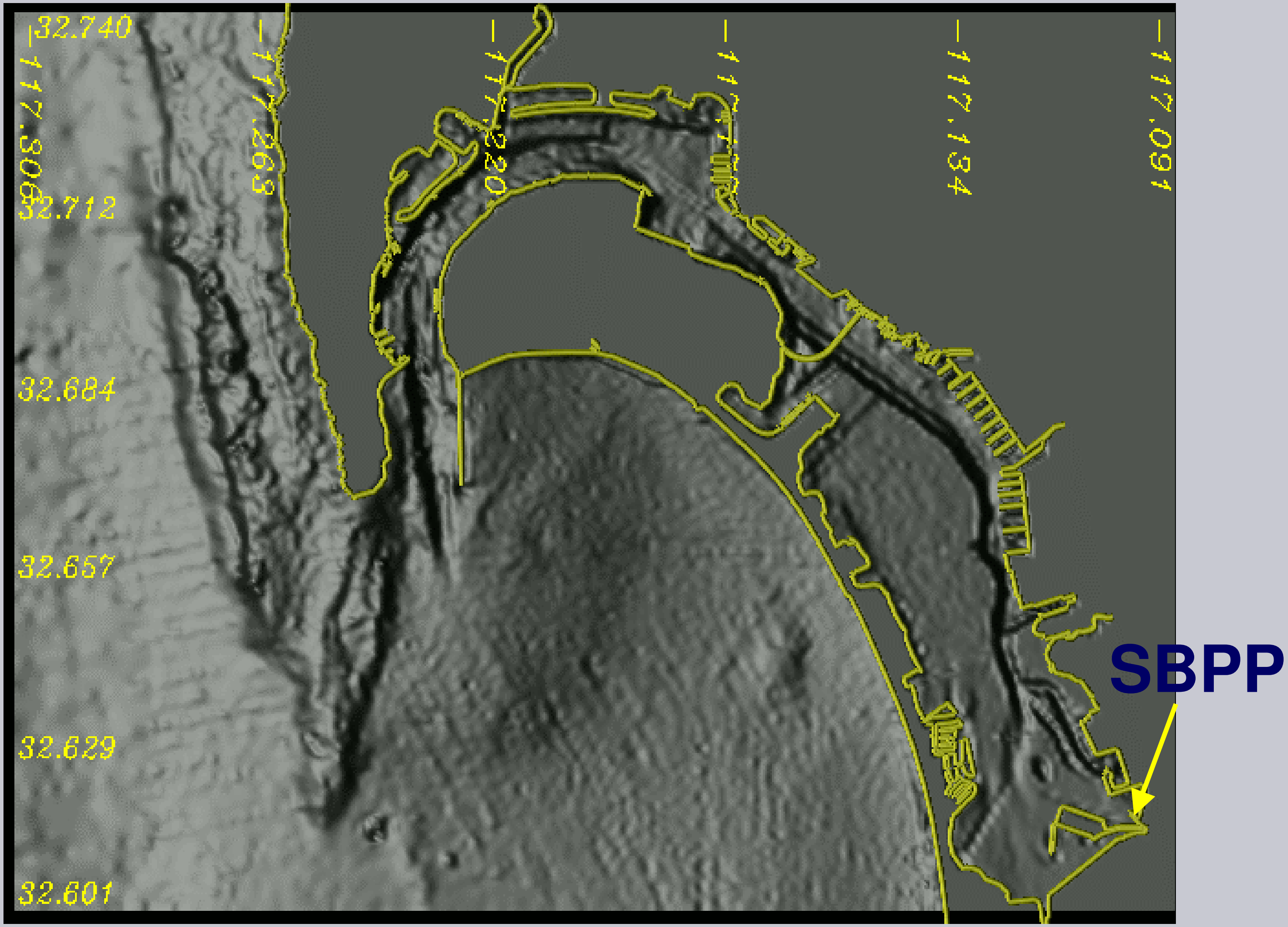
## San Diego Bay Tidal Dispersion

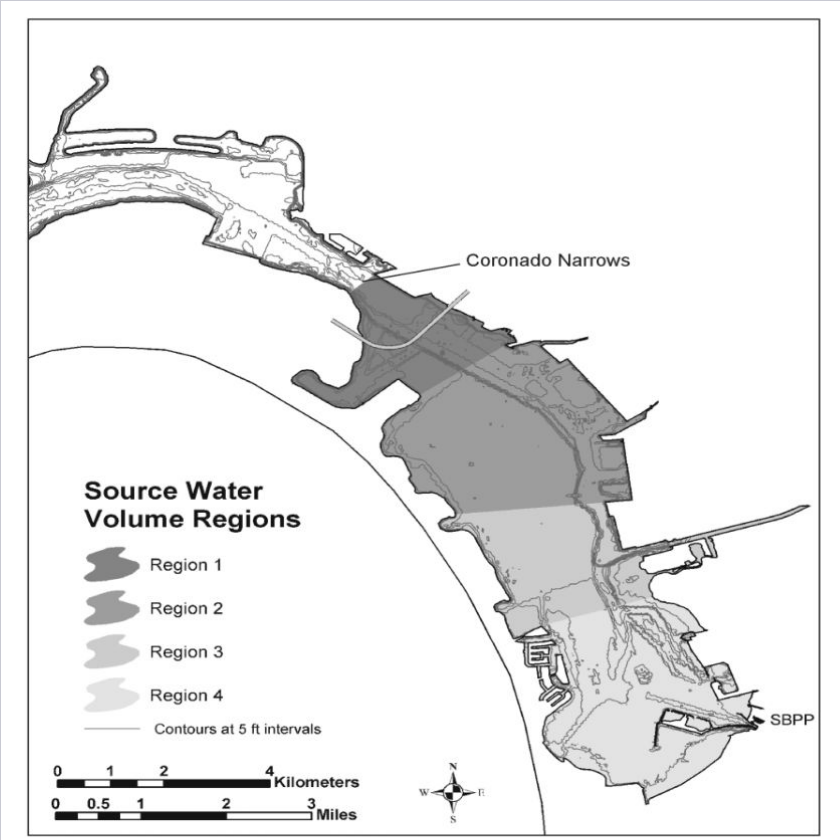



- Model estimates of time required for 50% tidal exchange
- 600-1000 hrs for south San Diego Bay

# Closed Estuarine System

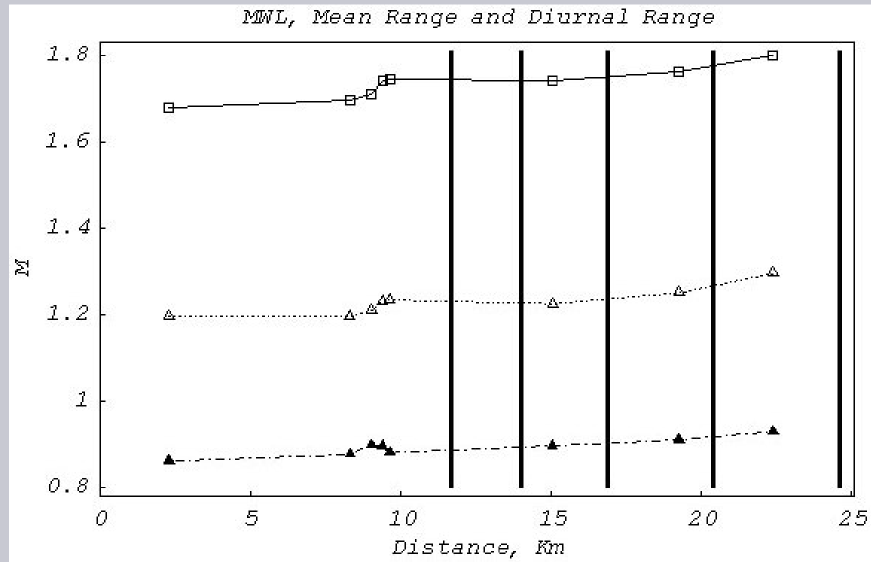
## San Diego Bay Bathymetry






# Closed System

## San Diego Bay Bathymetry




| Region | Datum | Height (MLLW) ft | Height (MLLW) m | Area $m^2$ | Area $ft^2$ | Volume $m^3$ | Volume $ft^3$ |
|---|---|---|---|---|---|---|---|
| 1 | MWL | 2.93 | 0.90 | 4,241,241 | 45,656,798 | 33,754,018 | 1,192,185,160 |
| 2 | MWL | 2.94 | 0.90 | 10,173,006 | 109,512,412 | 70,387,388 | 2,486,068,457 |
| 3 | MWL | 2.99 | 0.91 | 6,355,524 | 68,417,214 | 25,060,179 | 885,120,494 |
| 4 | MWL | 3.05 | 0.93 | 9,556,875 | 102,879,765 | 20,410,508 | 720,895,066 |
| | | | **Total** | **30,326,646** | **326,466,189** | **149,612,092** | **5,284,269,177** |

# SBPP ETM Model Data

| urvey Date | EA (#/$m^3$) | Estimated Number Entrained | Source Water (#/$m^3$) | Estimated Source Water | *PE* | Survey Period (days) | Source Water Population for Period | Source Population Proportion (*f*) | $=f_i(1-PE_i)^d$ |
|---|---|---|---|---|---|---|---|---|---|
| 28-Feb-01 | 2.143 | 4,877,000 | 5.712 | 8.546E+08 | 0.0057 | 41 | 3.504E+10 | 0.2165 | 0.1900 |
| 29-Mar-01 | 1.069 | 2,433,000 | 3.643 | 5.451E+08 | 0.0045 | 29 | 1.581E+10 | 0.0977 | 0.0882 |
| 17-Apr-01 | 1.997 | 4,544,000 | 2.794 | 4.180E+08 | 0.0109 | 19 | 7.942E+09 | 0.0491 | 0.0382 |
| 16-May-01 | 2.036 | 4,633,000 | 1.770 | 2.649E+08 | 0.0175 | 29 | 7.682E+09 | 0.0475 | 0.0317 |
| 14-Jun-01 | 3.747 | 8,525,000 | 2.311 | 3.458E+08 | 0.0247 | 29 | 1.003E+10 | 0.0620 | 0.0350 |
| 26-Jul-01 | 4.047 | 9,208,000 | 2.740 | 4.100E+08 | 0.0225 | 42 | 1.722E+10 | 0.1064 | 0.0633 |
| 23-Aug-01 | 0.648 | 1,475,000 | 2.609 | 3.904E+08 | 0.0038 | 28 | 1.093E+10 | 0.0675 | 0.0619 |
| 25-Sep-01 | 1.057 | 2,406,000 | 2.307 | 3.452E+08 | 0.0070 | 33 | 1.139E+10 | 0.0704 | 0.0600 |
| 23-Oct-01 | 1.254 | 2,852,000 | 2.553 | 3.820E+08 | 0.0075 | 28 | 1.070E+10 | 0.0661 | 0.0557 |
| 27-Nov-01 | 1.655 | 3,764,000 | 2.390 | 3.576E+08 | 0.0105 | 35 | 1.252E+10 | 0.0773 | 0.0607 |
| 20-Dec-01 | 1.861 | 4,233,000 | 2.745 | 4.107E+08 | 0.0103 | 23 | 9.446E+09 | 0.0584 | 0.0461 |
| 17-Jan-02 | 3.554 | 8,087,000 | 3.132 | 4.686E+08 | 0.0173 | 28 | 1.312E+10 | 0.0811 | 0.0545 |
| | | | | Average = | 0.0118 | | | $P_M$= | 0.2147 |

Larval duration=23 days

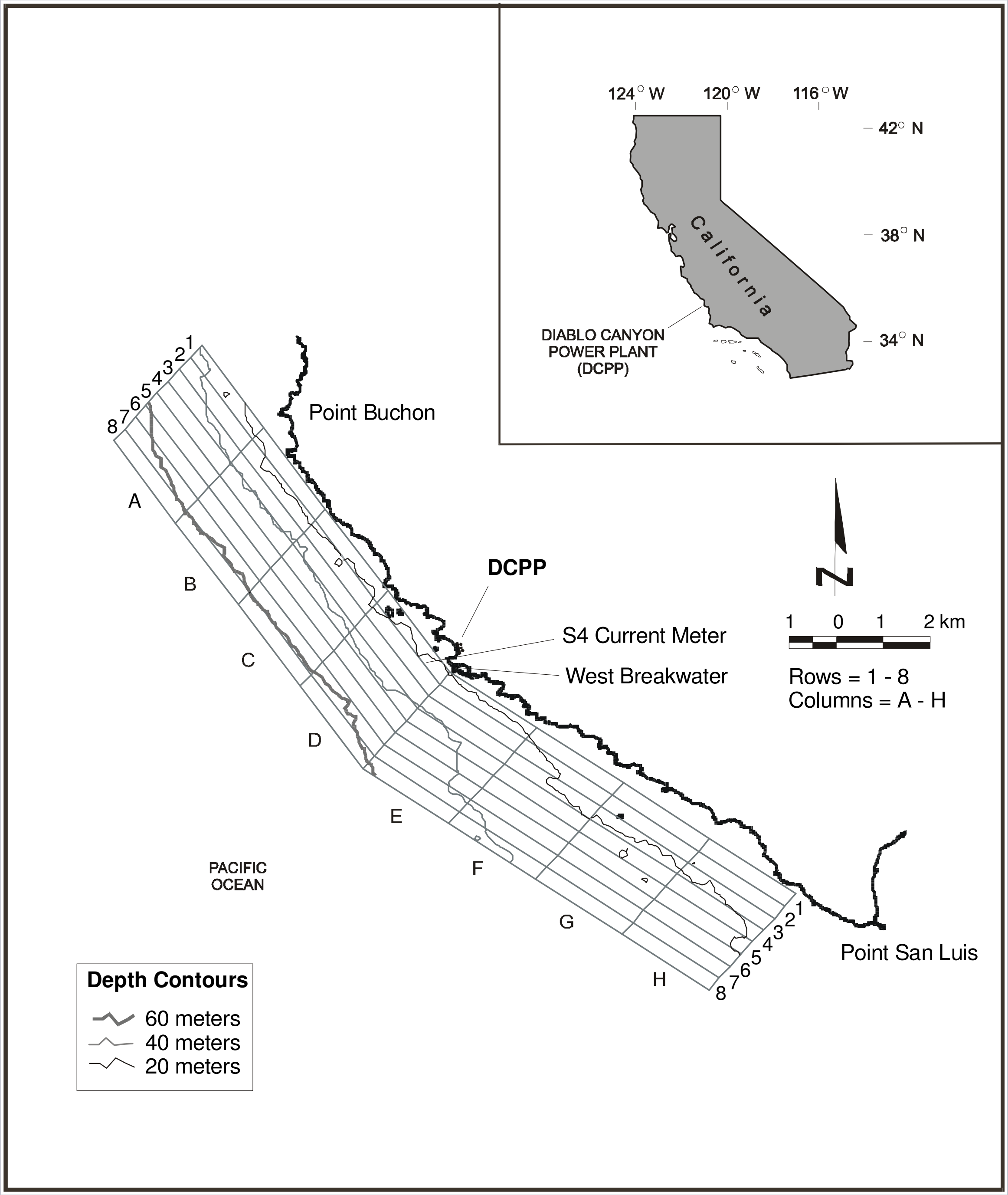
Note: little variation in PE

# Open Coastal System
## Diablo Canyon Power Plant

# Open Coastal System Diablo Canyon Power Plant

## Source Water Sampling

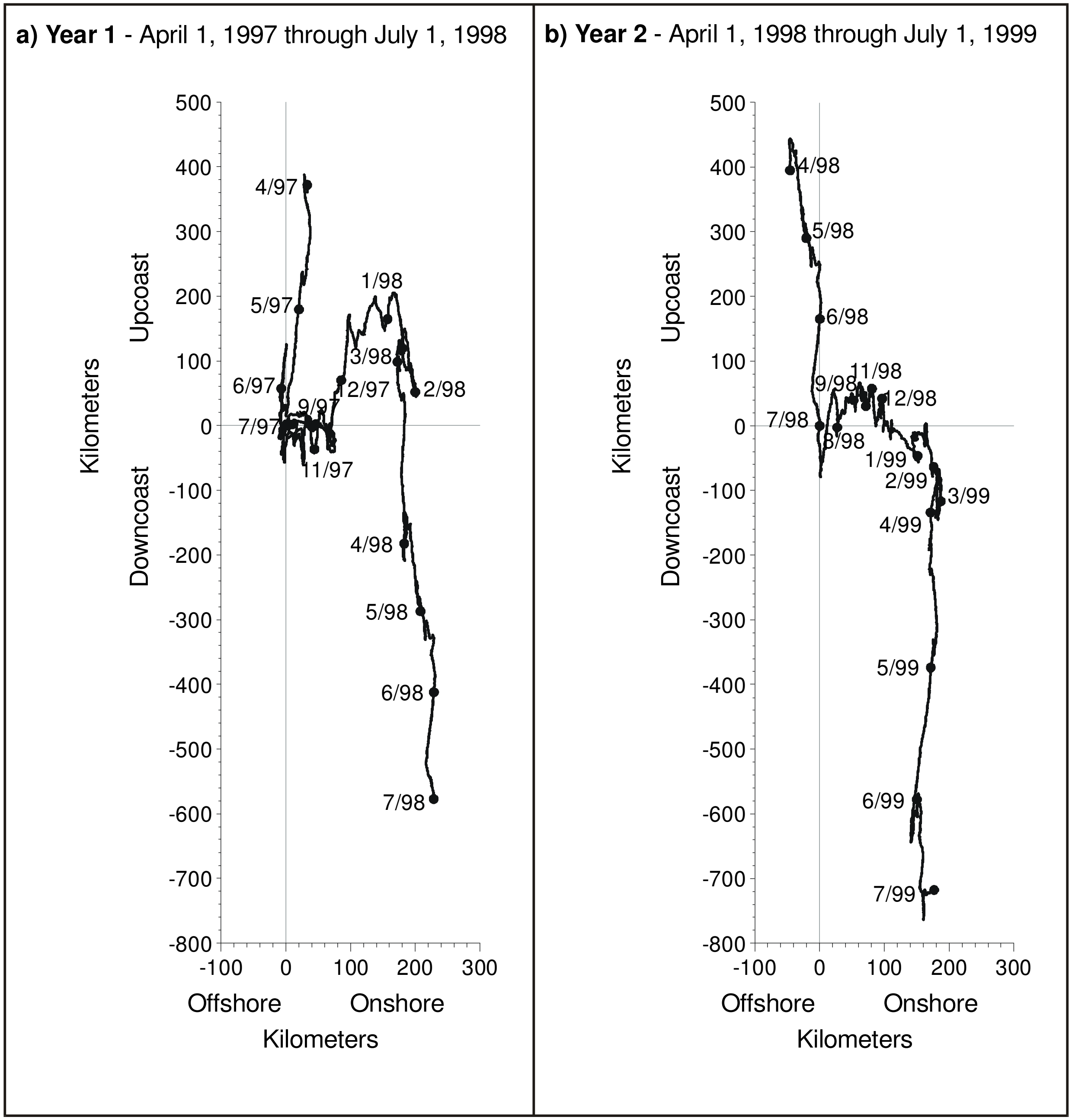
- 64 stations in 3 km x 17 km grid
- Sampled monthly over two years



# Open Coastal System

## Diablo Canyon Power Plant

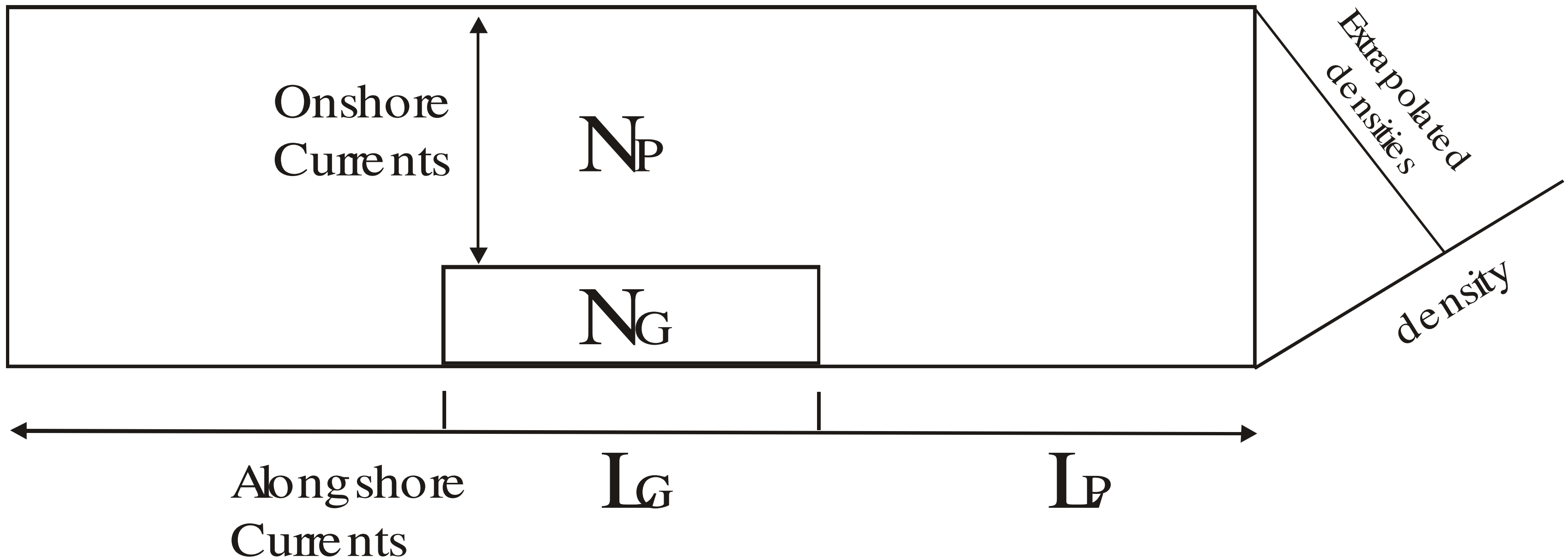
Cumulative Current Displacement



# Open Coastal System

## Diablo Canyon Power Plant

### Source Water Extrapolations

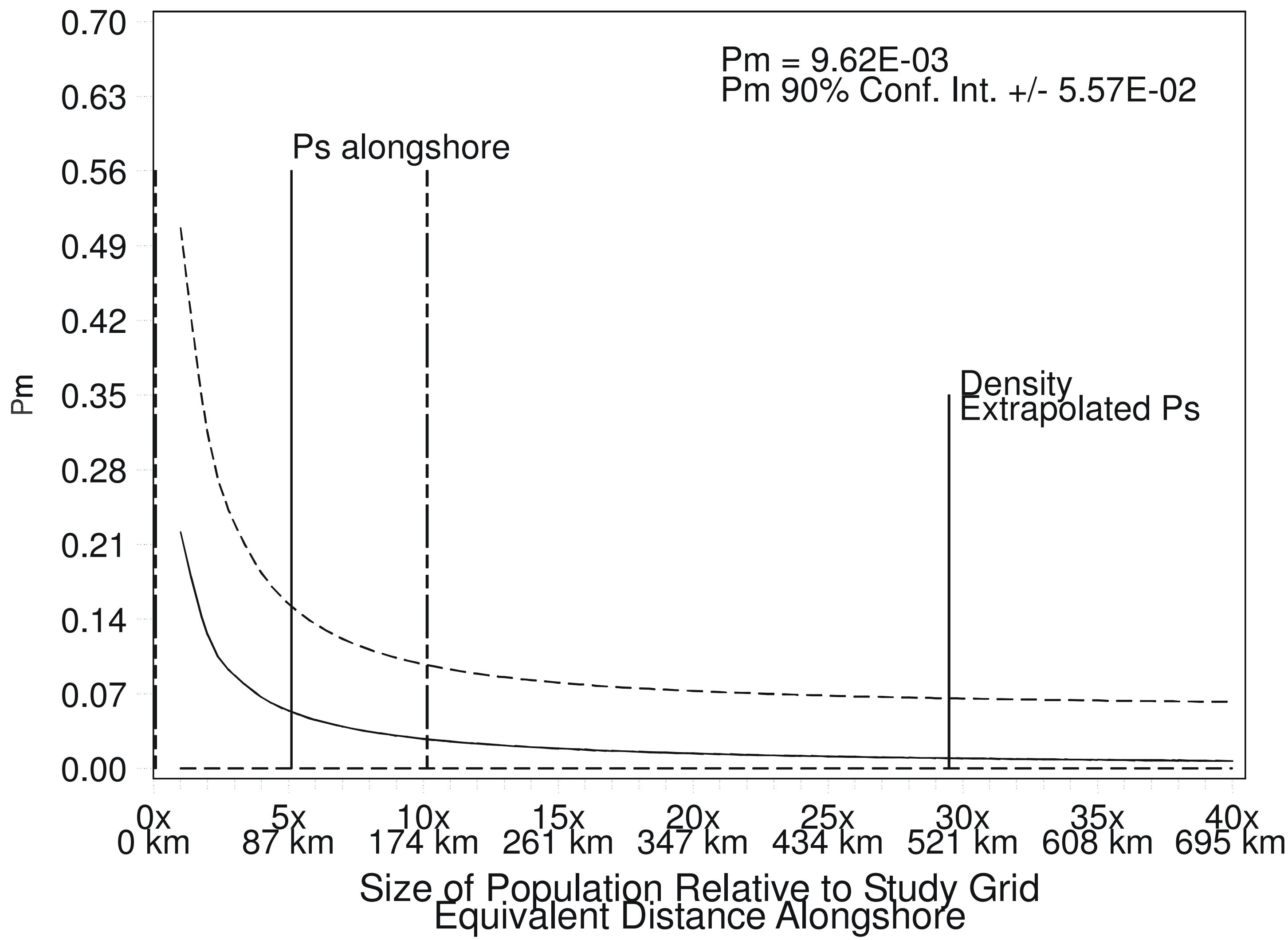



Nearshore $P_S = \frac{L_G}{L_P}$

Offshore $P_S = \frac{N_G}{N_P}$

# Open Coastal System

## Diablo Canyon Power Plant

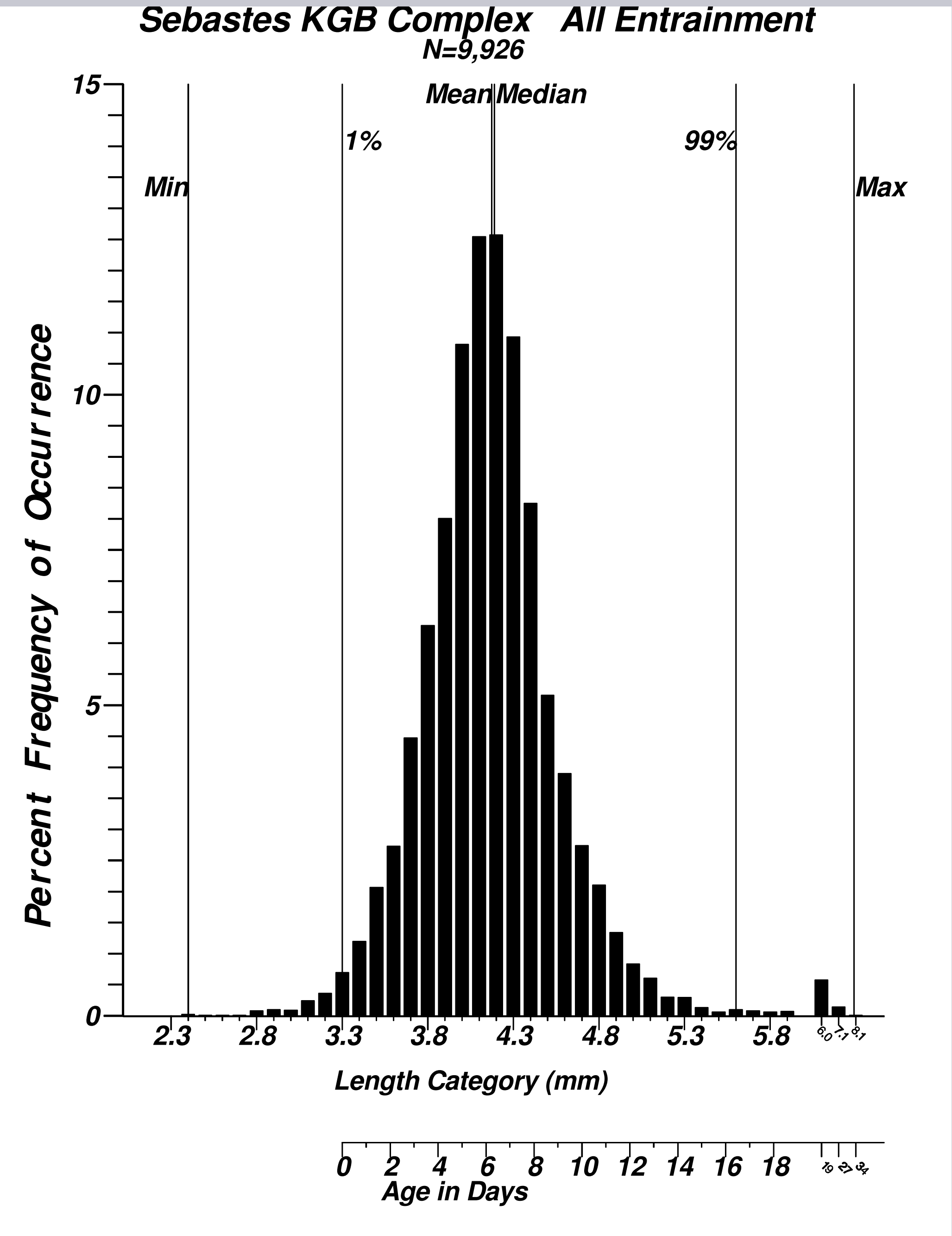


# Open Coastal Systems

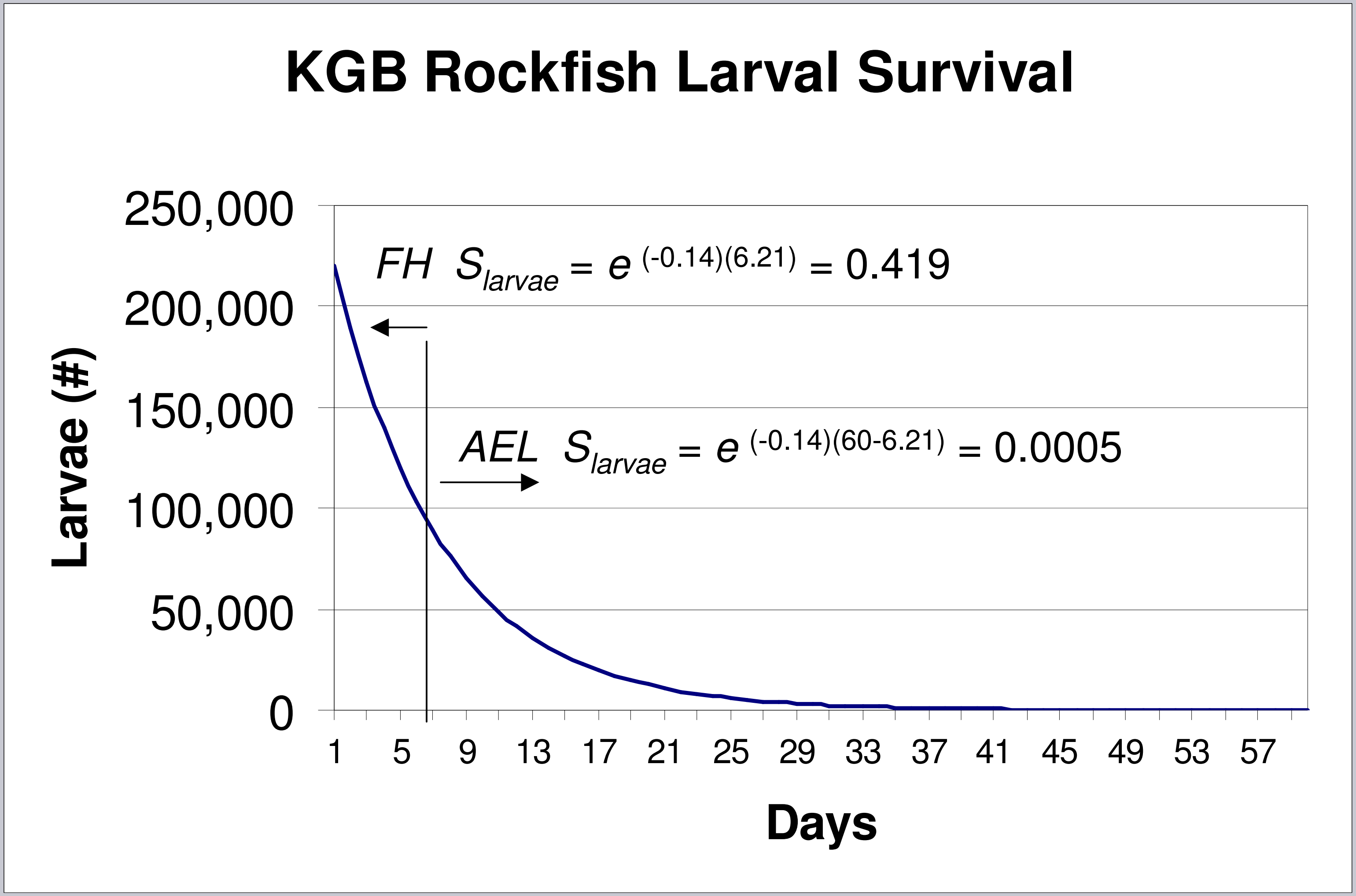
# Entrainment Assessment

Demographic Models

Length Frequency KGB Rockfishes



# Entrainment Assessment
## Demographic Models



# Entrainment Assessment

## Demographic Models
## Fecundity Hindcasting

$$FH = \frac{Entrainment_{Total}}{\prod_{j=1}^{n} Survival_j \bullet Fecundity_{Total}}$$

$$Fecundity_{Total} = \overline{Eggs / year} \bullet \left(\frac{Longevity - Maturation}{2}\right)$$

# Entrainment Assessment

## Fecundity Hindcasting

### KGB Rockfishes

- Adjusted Annual Entrainment = 275,000,000
- Average Annual Fecundity = 215,000
- Longevity = 15 yr
- Maturation = 5 yr
- Larval Survival – instantaneous daily mortality rate of 0.14 $d^{-1}$ for blue rockfish = 0.419
- Larval growth rate of 0.14 $d^{-1}$ for brown rockfish – to estimate larval duration

# Entrainment Assessment

## Fecundity Hindcasting

### KGB Rockfishes

$$FH = 617 = \frac{275{,}000{,}000}{1.0 \bullet 1.0 \bullet 0.419 \bullet 213{,}000 \bullet \frac{(15-5)}{2}}$$

egg survival (first 1.0) — yolk-sac survival (second 1.0)

# **Entrainment Assessment**

## Demographic Models

## Adult Equivalent Loss

$$AEL = ( Entrainment_{total} )$$

$$(S_{Early\ Larvae}) \ (S_{Late\ Larvae}) \ (S_{Early\ Juv.}) \ (S_{Late\ Juv})_{.} \ (S_{Pre\text{-}Recruits})$$

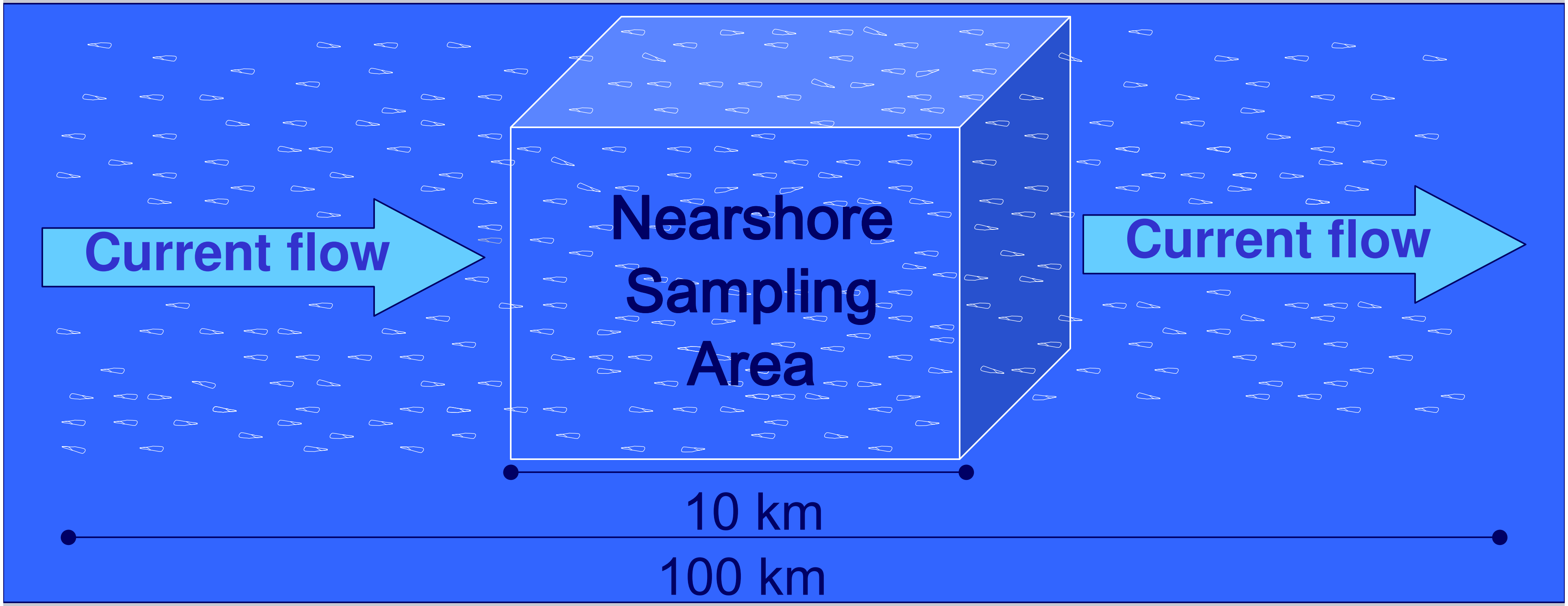
# **Entrainment Assessment**
## Demographic Models
## Adult Equivalent Loss

$$AEL = 1{,}120 = (275{,}000{,}000)\ (0.145)\ (0.0408)\ (0.00823)\ (0.125)\ (0.670)$$

$$AEL \approx 2\ (FH)$$

$$AEL = 1{,}120 \approx 2\ (FH = 617)$$

# Conceptualization of *ETM* and *APF*




$P_S$ = 10 km/100 km or 0.10

If $P_M$ = 5%, *APF* = 5% of 100 km or 5 km

# Application of APF

- Requires determining area of adult habitat in extrapolated source water
  - Example – along 100 km of coast there may only be 20 km of rocky reef supplying KGB rockfish larvae. APF is % of 20 km – not 100 km.
- May not be applicable to all habitats and species – open water pelagic habitat

# Application of APF

- Scale and context is important
- Two fishes have estimated entrainment losses ($P_M$) of 1% and 10%
  - Case 1: $P_M$ = 1% - northern anchovy has estimated source water of 1,000 $km^2$, results in APF = 10 $km^2$
  - Case 2: $P_M$ = 10% - kelp bass occupying limited kelp habitat around intake of 1 $km^2$, results in APF = 0.1 $km^2$

# **Entrainment Assessment** Guidelines

- Study Design
- Sampling and Processing
- Analysis

# Conclusions

- Important to apply flexible, site-specific approach to assessment
- Entrainment effects best evaluated using empirically based source water body information and the *ETM* model
- Effects less important with performance-based standards under new Rule