VIII. MAXIMIZING PRODUCTION THROUGH SEQUENTIAL REARING STRATEGIES

INTRODUCTION

The production potential of intensive fish culture systems, whether flow-through or recirculating, should be rated on the basis of how much feed they can "process" per day without exceeding specific, predetermined, water quality parameters such as ammonia nitrogen and its derivatives: nitrite and nitrate nitrogen, and carbon dioxide, suspended solids, and dissolved oxygen.

To realize optimum, i.e. maximum, annual production the daily feed allotment should be as close to the maximum as practical at all times. For example, if a system can "process" 120 kg of feed per day, the daily gain in biomass would be 120 kg for a feed conversion of one. For a feed conversion of 1.25, the daily gain would be 96 kg. Annual production would be 43,800 kg and 35,040 kg respectively if a steady state of maximum daily feed allotment could be maintained throughout the year and gains in production were removed daily. This is not practical, but the goal is to come as close to this maximum as possible. To accomplish this requires a sequential rearing strategy, where a new group of fish, a new cohort, is introduced into the system at regular time intervals.

Summerfelt et al. (1993) describe and model a sequential rearing strategy where market-size fish are selectively harvested from the entire system, irrespective of their location within the system. This approach is used by catfish farmers to accomplish year round production through "cull" harvesting. The per area output can be more than doubled compared to traditional batch culture, where an entire pond is harvested at the end of the growing cycle, and is then restocked with a new batch of fingerlings. The annual output for a one-year batch culture production cycle is basically equal to the carrying capacity.
Most public hatcheries use the batch culture strategy as they mimic the natural spawning cycle of fish intended for release into the natural environment.

The model presented here uses routine fish cultural data, such as growth rates, feed conversions, feeding levels, condition factors, and mortality rates. These data are species and facility specific and often show some variation from growing season to growing season. However, established fish farms should have reliable information for these parameters.

METHODS

Five different culture strategies are presented. They are (1) single cohort or batch culture, (2) two cohort, (3) four cohort, (4) six cohort, and (5) twelve cohort sequential rearing culture. The model is based on the following assumptions:

(a) The system can “process” a maximum of 120 kg of feed per day (MFd = 120).
(b) The Feed Conversion is 1.25 (FC = 1.25), the Feed Efficiency is 80% (FE = 80).
(c) The rearing water Temperature is a constant 15°C (T = 15).
(d) The Temperature Unit Growth rate is 0.006 cm/d (TUG = 0.006). The daily growth rate equals the average daily temperature times the temperature unit growth rate.
(e) The daily growth rate is 0.09 cm (ΔL = 0.09).
(f) The condition factor is 0.0100 (k = 0.0100). It is assumed to remain constant throughout the rearing cycle.
(g) The beginning weight is 2.75 g (W₁ = 2.75).
(h) The harvest weight is 500 g (Wₜ = 500).
(i) The beginning length is 6.5 cm (L₁ = 6.50).
(j) The harvest length is 36.84 cm (Lₜ = 36.84).
(k) The length of the rearing cycle is 337 days (RC = 337).
(l) Cohorts are introduced at equal time intervals during a rearing cycle.
(m) For multi-cohort rearing the number of fish are the same for each cohort.
If a fish is stocked at an initial length ($L_i$) and grown until harvested at a final length ($L_f$), then the length of the rearing cycle (RC) can be estimated by dividing the length gain during the rearing cycle ($L_f - L_i$) by the constant daily increase in length ($\Delta L$).

$$RC[\text{day}] = \frac{L_f - L_i}{\Delta L}$$  \hspace{1cm} (1)

The feeding level is determined with the formula developed by Westers (1987) and is expressed in percent body weight or biomass (%BW).

$$\%BW = \frac{(Tx300xTUGxFC)}{(W/k)^{1/3}}$$  \hspace{1cm} (2)

The value of the numerator is a constant because the values for temperature, temperature unit growth rate, and feed conversion are assumed to remain constant throughout the rearing cycle. This value is 33.75. The denominator represents the length of the fish, but because samples are measured as weight, rather than length, the equation uses weight and the condition factor, k.

**Single Cohort, Batch Culture**

Fish are stocked into the facility only once per year, and grow through one rearing cycle to a maximum weight of 500 g and length of 36.84 cm. Their final feed requirement, according to equation 2, is 0.91%BW/d. The maximum permissible biomass (MBM) can be estimated by:

$$MBM = \frac{MFD \times 100}{\%BW}$$  \hspace{1cm} (3)
The maximum number of fish (N) can now be determined by:

\[
N = \frac{MBM \times 1000 \text{ (g/kg)}}{W_h}
\]  
(4)

where 1000 represents g per kg.

or by:

\[
N = \frac{MFd \times 1000}{Fd/Fs}
\]  
(5)

Where Fd/Fs equals gram of feed per fish per day, and is calculated with:

\[
Fd/Fs = \frac{\%BW \times W}{100}
\]  
(6)

When only one batch is produced annually, the maximum annual production (MAP) is equal to the maximum biomass the system can support. Thus, MAP also equals the carrying capacity for batch culture. One common assumption with this type of model is that the growth rate is constant over time for the entire cohort of fish.

**Multi-cohort, Sequential Rearing Culture**

A sequential rearing strategy has a dual benefit: increased production and steady, continuous output over time. The model presented here only requires estimates of fish lengths, weights, and feeding levels for each cohort at an instantaneous point in the rearing cycle, i.e., the
point at which maximum loading occurs. Lengths and weights for each cohort are obtained by:

\[ L_t = L_1 + \Delta L_t \]  \hspace{1cm} (7)

\[ W_t = kL_t^3 \]  \hspace{1cm} (8)

Where \( t \) is the age of the cohort in days. For the multi-cohort examples that follow, maximum loading occurs on day-337, just prior to harvesting the first cohort of the rearing cycle.

The feeding level for individual cohorts is determined by equation (2). Based on initial parameters, and equations (6-8), a simple table can be constructed giving values of \( L_t, W, \%BW \), and \( Fd/Fs \) for each cohort at the point of maximum loading.

An equation for estimating the number of fish in each cohort (\( N \)) can be derived from the maximum amount of feed (\( MFd \)) the system can process, and feeding levels of all cohorts in the system. Complexity is reduced through the assumption that all cohorts contain the same number of fish (\( N = N_{\text{cohort-1}} = N_{\text{cohort-2}}, \text{ etc...} \)).

\[ MFd = \sum_{i=1}^{c} \text{feed}_i \]

\[ = \sum_{i=1}^{c} N_i x(Fd/Fs)_i \]

\[ N = \frac{MFd \times 1000}{\sum_{i=1}^{c} (Fd/Fs)_i} \]  \hspace{1cm} (9)
The value of 1000 in equation (9) converts grams to kilograms.

The maximum annual production (MAP) for a selected sequential rearing strategy can then be estimated by:

\[
\text{MAP} = \frac{N \times W_h \times C \times 365}{1000 \times \text{RC}}
\]  

(10)

where \(C\) is equal to the number of cohorts in the rearing cycle.

Equations 7-10 define the basic mathematical concepts behind the simplified sequential rearing model. In later sections we present results from 2, 4, 6, and 12 cohorts per rearing cycle based on historical data, and demonstrate how fish producers might use this model to help optimize the production potential for their individual systems.

**Effects of Growth Rates On Production**

To examine the effect of growth rate on production we used slower growing fish in a six-cohort rearing strategy.

The parameters of slower growing fish are as follows:

(a) The rearing Temperature is \(10^\circ\text{C} \) (T=10)

(b) The Temperature Unit Growth rate is 0.005 cm (TUG = 0.005)

(c) The daily growth rate is 0.05 cm (\(\Delta L = 0.05\))

(d) The length of the Rearing Cycle is 607 days (RC = 607)

(e) A new cohort is introduced every 101 days (t = 101)

(f) The %BW is 18.75/L (300 \times 10 \times 0.005 \times 1.25/L)
Mortality

Seasoned fish farmers know nearly all cohorts of fish experience mortality losses throughout the rearing cycle. Often mortality rates vary between cohorts and between life stages within cohorts. Based on past experience or historical data, a fish farmer can estimate annual and/or age specific mortality rates in the form of percentages of fish expected to survive from one stage to the next. To examine effects of mortality on the model we assumed constant mortality from year to year, but higher mortality for younger fish than older fish. This can easily be demonstrated for the 2-cohort model.

Assumptions:

(a) Mortality rate for the first 168 days is 8 percent \( (m_1 = 0.08) \).

(b) Mortality rate for days 169-337 is 5 percent \( (m_2 = 0.05) \).

(c) Numbers of fish at age are equal between cohorts.

As in the case of the multi-cohort model, length, weight, and feed levels can be estimated from equations (7), (8), and (2).

The number of fish on day 337 equals the number of fish on day 168 less five percent. This can be shown with equation 11.

\[
N_{t=337} = N_{t=168} \times (1 - m_2)
\]

(11)

Maximum loading occurs just prior to harvest, which is on day-337 for the examples presented here. The maximum amount of feed that the system can handle must be distributed between the number of cohorts in the system. For a two-cohort rearing strategy:

\[
MF_{d} = Feed_{\text{cohort-1}} + Feed_{\text{cohort-2}}
\]
On day-337, the age of cohort-1 is 337 d, and the age of cohort-2 is 168 d. The maximum amount of feed can be then related to the number and age of individual cohorts:

\[ \text{MFd} = \frac{N_{t=337} \times \text{Fd}}{F_{s_{\text{cohort-1}}}} + \frac{N_{t=168} \times \text{Fd}}{F_{s_{\text{cohort-2}}}} \]

Through substitution of equation (11) into the above equation, and after rearranging to solve for \( MN_{t=168} \), the number of fish at the midpoint of the rearing cycle can be obtained:

\[ N_{t=168} = \frac{\text{MFd} \times 1000}{\frac{\text{Fd}}{F_{s_{\text{cohort-1}}} \times (1-m_1)} = \frac{\text{Fd}}{F_{s_{\text{cohort-2}}}}} \]  

Finally, the initial stocking numbers for each cohort entering the system can be estimated by:

\[ N_{t=1} = \frac{N_{t=168}}{(1-m_1)} \]  

RESULTS

Single Cohort, Batch Culture

A single cohort of fish enters the system on day 1; the fish grow through one rearing cycle in 337 d to a harvest size of 500g. From equation (3) the maximum biomass is determined to be 13,187 kg, and the maximum number of fish that should be stocked into the system is 26,374 fish (equation 4).

Batch culture normally requires a full rearing cycle, sometimes a full year, to achieve maximum biomass and to harvest the fish. Feed input to the system approaches the maximum feed allotment the system can process only once per rearing cycle. Thus, through batch culture strategies, the fish farmer is not optimizing the biological efficiency of the culture system.
Multi-cohort, Sequential Rearing Culture

Model estimates for a 2-cohort rearing strategy is shown in Table 1. One assumption of this model is that the number of fish per cohort (MN) is the same for each cohort. Maximum feed input to the system should occur when fish are ready for harvest (i.e., at maximum biomass). Equation (9) states that at the time of maximum daily feed (120 kg or 120,000 g feed), the feed requirements of all cohorts in the system should equal this maximum. Assuming $MN_i = MN_{II}$ and cohort II starting at 168 we can write:

\[
1.57 \text{MN} + 4.55 \text{MN} = 120,000
\]

\[
6.13 \text{MN} = 120,000
\]

\[
\text{MN} = 19,576
\]

All critical information for two or more cohorts is summarized in tabular form (Tables 1 through 4) and graphically presented in Figures 1 through 4.

The results of the five rearing strategies are summarized in Table 5. Column 3, "ratio" gives the ratios between the maximum annual production realized with the different rearing strategies and the maximum biomass the system can support, i.e., the carrying capacity. In the single cohort, batch culture strategy, the maximum annual production equals the carrying capacity, thus its ratio is 1.0. The two-cohort program accomplishes an annual output that is 1.6 times as great as the one-time maximum biomass, (i.e., the system's maximum carrying capacity).

Column 5 (of Table 5), "kg/ch," lists the increase in production per cohort. As the number of cohorts increases, the gain per cohort decreases. Column 6 "%TMAP" shows the maximum, i.e. 100% efficiency. This theoretical maximum is realized if 120 kg feed could be
fed 365 d of the year. For a feed conversion of 1.25 (feed efficiency of 80%), the theoretical maximum annual production equals 35,040 kg \((120 \times 0.80 \times 365)\).

Column 7, "mean Fd/d" records the maximum average daily amount of feed realized at time of maximum biomass. The closer this is to the 120 kg, the more efficient the production.

**Effects of Growth Rates on Production**

Figure 5 graphically illustrates how diminishing returns on production are realized as the number of cohorts added to the rearing cycle increases. The maximum number per cohort \((N)\) and maximum annual production (MAP) for the slower growing fish were determined using equations 9 and 10.

\[
N = \frac{120,000}{7.37} = 16,290
\]

\[
MAP = \frac{(16,290 \times 500 \times 6 \times 365)}{(1000 \times 607)} = 29,386
\]

Notice that this group requires an 80% increase in fingerlings, 7247 fish, over the faster growing fish (Table 3), but the maximum annual production remains the same. The maximum biomass for the slower growing fish under steady state conditions is 1.21 times the one of the faster growing species in Table 3. Thus, for equal rearing densities the rearing volume must be 1.21 times greater.

**Mortality**

Mortality effects were incorporated in the model for a 2-cohort system. Equations (11)-(13) were used to estimate numbers of fish in the system over time. Taking mortality into account, initial stocking levels were estimated to be 22,108 in order to achieve the same MAP estimated for the basic two-cohort model. Thus, the basic model, without mortality, underestimated initial stocking levels by 12.9% as compared to the mortality incorporated model.


**DISCUSSION**

Contrary to what one might expect, faster growth rates do not result in greater annual production than slower growth rates, providing there is no difference in feed conversions. Once the maximum biomass has been attained, i.e., the steady biomass of a specific amount of daily feed allowance, the daily gain in fish flesh is the same, as long as feed conversions are identical. However, there are distinct disadvantages with slower growth rates. Slower growing fish require longer time periods and more fish per cohort to achieve steady state. As a result, more space is required, resulting in higher capital costs.

Non-mixed cohort rearing is preferred over mixed rearing in intensive aquaculture. Uniform size fish populations greatly expedite good feed management by producing less feed waste. This is an important environmental issue and a critical economic factor (Midlen and Redding 1998). Table 5 and Figure 5 clearly show diminishing returns with each additional cohort added to the program. The most significant increase per cohort added to a production program is to move from batch culture to two cohorts. The results show that this change in strategy increases production by 61%. The overall increase in production is 104% for four cohorts (26% per cohort), 123% for six cohorts (20.5% per cohort) and 145.5% for twelve cohorts (12% per cohort).

For a non-mixed sequential rearing strategy it appears from the above data that a program of two to six cohorts may be optimal. Much depends on the availability of eggs or fingerlings throughout a year, as well as species’ domestication, broodstock programs, number of rearing units, and economics. At the very least, fish culturists should attempt to go from batch culture to one of two cohorts.

Routine fish culture data has been used in this simplified method for sequential rearing strategies. Values have been rounded to simplify hand calculations. Constant values have been
used throughout the rearing cycle for temperature, feed conversion, growth rate, and condition factor. This is not realistic, but it makes the presentation less complicated, less confusing. The mechanism presented is valid and can be applied where these parameters change during the production cycle. It is of great importance for production managers to establish a reliable database for these fish culture parameters. Today’s computers can readily deal with the variables, including mortalities.
Table 1. Projected fish length, weight, feed percent body weight (%BW), feed per fish (Fd/Fs), biomass per cohort (BM/ch) and maximum feed per cohort (MFd/ch) for a two-cohort rearing strategy at the end, day-337, of the first cohort’s rearing cycle.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Age (d)</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>%BW</th>
<th>Fd/Fs (g)</th>
<th>BM/ch (kg)</th>
<th>MFd/ch (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>168</td>
<td>21.62</td>
<td>101</td>
<td>1.56</td>
<td>1.57</td>
<td>1,980</td>
<td>30.9</td>
</tr>
<tr>
<td>1</td>
<td>337</td>
<td>36.84</td>
<td>500</td>
<td>0.91</td>
<td>4.55</td>
<td>9,804</td>
<td>89.1</td>
</tr>
<tr>
<td>Total</td>
<td>6.12</td>
<td>11,784</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13
Table 2. Length, weight, feed percent body weight (%BW), feed per fish (Fd/Fs), biomass per cohort (BM/ch) and maximum feed per cohort (MFd/ch) for a four-cohort rearing strategy.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Age (d)</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>%BW</th>
<th>Fd/Fs (g)</th>
<th>BM/ch (kg)</th>
<th>MFd/ch (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>84</td>
<td>14.06</td>
<td>27.8</td>
<td>2.4</td>
<td>0.67</td>
<td>345</td>
<td>8.3</td>
</tr>
<tr>
<td>3</td>
<td>168</td>
<td>21.62</td>
<td>101</td>
<td>1.56</td>
<td>1.57</td>
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<td>525</td>
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<td>3,080</td>
<td>35.7</td>
</tr>
<tr>
<td>1</td>
<td>337</td>
<td>36.84</td>
<td>500</td>
<td>0.9</td>
<td>4.55</td>
<td>6,210</td>
<td>56.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total: 9.67</td>
<td>Total: 10,889</td>
</tr>
</tbody>
</table>
Table 3. Length, weight, feed percent body weight (%BW), feed per fish (Fd/Fs), biomass per cohort (BM/ch) and maximum feed per cohort (MFd/ch) for a six-cohort rearing strategy.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Age (d)</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>%BW</th>
<th>Fd/Fs (g)</th>
<th>BM/ch (kg)</th>
<th>MFd/ch (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>56</td>
<td>11.54</td>
<td>15.4</td>
<td>2.92</td>
<td>0.45</td>
<td>139</td>
<td>4.1</td>
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<tr>
<td>5</td>
<td>112</td>
<td>16.58</td>
<td>45.6</td>
<td>2.04</td>
<td>0.93</td>
<td>412</td>
<td>8.4</td>
</tr>
<tr>
<td>4</td>
<td>168</td>
<td>21.62</td>
<td>101</td>
<td>1.56</td>
<td>1.57</td>
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<td>280</td>
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<td>2,876</td>
<td>30.5</td>
</tr>
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<td>0.91</td>
<td>4.55</td>
<td>4,522</td>
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<td><strong>Total</strong></td>
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Table 4. Length, weight, feed percent body weight (%BW), feed per fish (Fd/Fs), biomass per cohort (BM/ch) and maximum feed per cohort (MFd/ch) for a twelve-cohort rearing strategy.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Age (d)</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>%BW</th>
<th>Fd/Fs (g)</th>
<th>BM/ch (kg)</th>
<th>MFd/ch (kg)</th>
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</thead>
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<td>12</td>
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<tr>
<td>11</td>
<td>56</td>
<td>11.54</td>
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<td>77</td>
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<tr>
<td>10</td>
<td>84</td>
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<tr>
<td>9</td>
<td>112</td>
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<td>21.62</td>
<td>101</td>
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<td>1.96</td>
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<td>9.7</td>
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</tr>
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<td>0.91</td>
<td>4.55</td>
<td>2,492</td>
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</tr>
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</table>

Total 24.20 10,283 120.0
Table 5. Number of cohorts in a rearing strategy, maximum annual production (MAP), ratio of MAP to the maximum biomass for a one-cohort strategy, initial stocking levels (MN), increase in production per cohort (kg/ch), MAP as a percentage of the theoretical maximum annual production (%TMAP), and mean daily feed per fish (Mean Fd/d).

<table>
<thead>
<tr>
<th>Cohorts</th>
<th>MAP (kg)</th>
<th>Ratio</th>
<th>MN</th>
<th>kg/ch</th>
<th>%TMAP</th>
<th>Mean Fd/d (kg)</th>
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<td>-</td>
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</tr>
</tbody>
</table>
References


Figure 1. Total production (heavy line) and individual cohort production (thin line) in biomass for a two-cohort rearing strategy based on a 337-day rearing cycle.
Figure 2. Production in biomass for a twelve-cohort rearing strategy based on a 337-day rearing cycle.
Figure 3. Maximum Annual Production (MAP), and number of fish per cohort from sequential rearing strategies altering the number of cohorts per rearing cycle.
Maximizing Production

The capacity of a fish production system should be rated on how much feed per day it can "process" without exceeding pre-determined water quality parameters.

Assume: Can "process" 120 kg feed per day (264 lb)

1. FC = 1.0 → Daily gain = 120 kg
2. Remove the gain daily
3. $365 \times 120 \text{ kg} = 43,800 \text{ kg} (96,360 \text{ lb})$
   1. FC = 1.25 (FE = 80%) → Gain = 96 kg
   2. MAP = $365 \times 96 = 35,040 \text{ kg} (77.088)$

This scenario is not practical – but...
How close can we come to it?
Maximizing Facility Output
Through a sequential rearing program.

a) MFd = 120 kg  (264 lb)
b) FC = 1.25    FE = 80%
c) T = 15°C  (59°F)
d) TUG = 0.006 cm
e) \( \Delta L = 0.09 \text{ cm} \)  \( (0.006 \times 15^\circ\text{C}) \)
f) \( k = 0.0100 \)
g) \( W_1 = 2.75 \text{ g} \)  (165/lb)
h) \( W_H = 500 \text{ g} \)  (1.1 lb)
i) \( L_1 = 6.5 \text{ cm} \)  (2.6”)
j) \( L_H = 36.84 \text{ cm} \)  (14.5”)
k) \[ RC = 337d \left( \frac{L_H - L_I}{\Delta L} \right) \]

l) New cohort at equal time periods.
m) Same number of fish per cohort.

These are Assumptions

Will apply to: (1) Batch culture (conserv. hatcheries)
(2) Two cohort
(3) Four cohort
(4) Six cohort
(5) Twelve cohort strategies
Sequential Rearing Strategies

\[ \%BW = \left( \frac{T \times 300 \times TUG \times FC}{W/K} \right)^{1/3} \]

\[ \%BW = \left( \frac{300 \times \Delta L \times FC}{L} \right) \]

\[ \%BW = 33.75/L \]

Batch as practiced in conservation hatcheries as they mimic the natural rearing cycles of the fish (but it can depend on their programs)

At final weight and length (500g & 36.84 cm) the \( \%BW = 0.91\% \)
Possible maximum biomass (MBM) based on maximum feed per day (MFd) is:

\[
MBM = \frac{(MFd \times 100)}{%BW}
\]

MBM = \frac{12,000}{0.91} = 13,187 \text{ kg}

The maximum number of fish (N):

\[
N = \frac{(MBM \times 1000)}{WH}
\]

\[
N = \frac{13,186,800g}{500g/\text{fish}} = 26,373 \text{ fish}
\]
Batch Culture  (Cont.)

English:  \[ MF_{d} = 264 \text{ lb} \quad W_{h} = 1.1 \text{ lb} \]

\[
MBM = \left( 264 \times 100 \right)/0.91 = 29.010 \text{ lb} \\
N = (29,010)/1.0 = 26,373 \\
\left( N = \frac{MBM}{W_{h}} \right)
\]

MAP (Maximum Annual Production) is the same as the maximum carrying capacity.

(Fd/Fs): Feed per fish per day is:
\[
Fd/Fs = \left( \%BW \times W \right)/100
\]
For 500g fish: \( (0.91 \times 500)/100 = 4.55g \)

\( (0.91 \times 1.1)/100 = 0.01 \text{ lb} \)

Because of the small values when expressed as lb Fd/Fs will be expressed in gram (g).

\[
N = \frac{(MFd \times 1000g/kg)}{Fd/Fs}
\]

\[N = 120,000/4.55 = 26,373 \text{ fish in system}\]
Two Cohort Strategy

Table shows fish length, weight, %BW, Fd/Fs, BM/ch, Max. feed per cohort (MFd/ch)       RC = 337

<table>
<thead>
<tr>
<th>Cohort #</th>
<th>Age d</th>
<th>L cm</th>
<th>W g</th>
<th>%BW</th>
<th>Fd/Fs g</th>
<th>BM/ch kg</th>
<th>MFd/ch kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>168</td>
<td>21.6</td>
<td>101</td>
<td>1.56</td>
<td>1.57</td>
<td>1,980</td>
<td>30.9</td>
</tr>
<tr>
<td>1</td>
<td>337</td>
<td>36.8</td>
<td>500</td>
<td>0.91</td>
<td>4.55</td>
<td>9,804</td>
<td>89.1</td>
</tr>
</tbody>
</table>

Totals: 6.12 11,784 120

\[ W = kL^3 \]

\[ \%BW = 33.75/L \]

\[ \text{Fd/Fs} = (\%BW \times W)/100 \]

\[ \text{BM/ch} = (N \times W)/1000 \]
## Four Cohort Strategy

<table>
<thead>
<tr>
<th>CH #</th>
<th>Age d</th>
<th>L cm</th>
<th>W g</th>
<th>%BW</th>
<th>Fd/Fs g</th>
<th>BM/ch kg</th>
<th>MFd/ch kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>84</td>
<td>14.1</td>
<td>27.8</td>
<td>2.4</td>
<td>0.67</td>
<td>345</td>
<td>8.3</td>
</tr>
<tr>
<td>3</td>
<td>168</td>
<td>21.6</td>
<td>101</td>
<td>1.56</td>
<td>1.57</td>
<td>1,254</td>
<td>19.5</td>
</tr>
<tr>
<td>2</td>
<td>252</td>
<td>29.2</td>
<td>248</td>
<td>1.16</td>
<td>2.88</td>
<td>3,080</td>
<td>35.7</td>
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<tr>
<td>1</td>
<td>337</td>
<td>36.8</td>
<td>500</td>
<td>0.91</td>
<td>4.55</td>
<td>6,210</td>
<td>56.5</td>
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</table>

**Total:** 9.67 10,889 120

\[ N = \frac{(120,000)}{9.67} = 12,410 \]

\[ MAP = \frac{(12,410 \times 500 \times 4 \times 365)}{(1000 \times 337)} \]

**MAP = 26,882 kg**

**Batch:** 13,187 kg (29,011 lb)

**2-Cohort:** 21,237 kg (46,722 lb)
## Six Cohort Strategy

<table>
<thead>
<tr>
<th>CH #</th>
<th>d</th>
<th>L</th>
<th>W</th>
<th>%BW</th>
<th>Fd/Fs</th>
<th>BM/ch</th>
<th>MFd/ch</th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td>56</td>
<td>11.5</td>
<td>15.4</td>
<td>2.9</td>
<td>0.45</td>
<td>139</td>
<td>4.1</td>
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<tr>
<td>5</td>
<td>112</td>
<td>16.6</td>
<td>45.6</td>
<td>2.1</td>
<td>0.93</td>
<td>412</td>
<td>8.4</td>
</tr>
<tr>
<td>4</td>
<td>168</td>
<td>21.6</td>
<td>101</td>
<td>1.6</td>
<td>1.57</td>
<td>913</td>
<td>14.2</td>
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<td>3</td>
<td>224</td>
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<td>31.7</td>
<td>318</td>
<td>1.1</td>
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<tr>
<td>1</td>
<td>337</td>
<td>36.8</td>
<td>500</td>
<td>0.9</td>
<td>4.55</td>
<td>4,522</td>
<td>41.2</td>
</tr>
</tbody>
</table>

**Totals:**

N = 120,000/13.27 = **9,043**

MAP = (9,043 x 500 x 6 x 365)/(1000 x 337)

MAP = **29,383 kg** \( (64,642 \text{ lb}) \)

Next: Comparing 5 production strategies.
### A Comparison of Five Rearing Strategies

<table>
<thead>
<tr>
<th>C</th>
<th>MAP kg</th>
<th>Ratio</th>
<th>N</th>
<th>kg/ch</th>
<th>%TMAP</th>
<th>Fd/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13,187</td>
<td>1.00</td>
<td>26,374</td>
<td>-</td>
<td>38</td>
<td>45.6</td>
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<tr>
<td>2</td>
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<td>1.60</td>
<td>19,608</td>
<td>8,050</td>
<td>61</td>
<td>73.2</td>
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<tr>
<td>4</td>
<td>26,902</td>
<td>2.04</td>
<td>12,419</td>
<td>4,572</td>
<td>77</td>
<td>92.4</td>
</tr>
<tr>
<td>6</td>
<td>29,383</td>
<td>2.23</td>
<td>9,043</td>
<td>3,239</td>
<td>84</td>
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<tr>
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<td>2.46</td>
<td>4,959</td>
<td>1,745</td>
<td>92</td>
<td>110.4</td>
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</tbody>
</table>

**Ratio:** Ratio of MAP to maximum biomass for batch culture, or maximum carrying capacity.

**kg/ch:** Increase in production per cohort.

**%TMAP:** MAP as a percentage of the theoretical MAP 
(\(96 \text{ kg/d} \times 365\text{d} = 35,040\text{ kg}\))

Finally – *Figure 1.*
\[ N = (\text{MFD} \times 1000) / \text{Fd/Fs} \]

\[ N = 120,000 / 6.12 = 19,608 \]

\[ \text{MAP} = (N \times W_H \times C \times 365) / (1000 \times RC) \]

\[ \text{MAP} = 19,608 \times 500 \times 2 \times 365) / (1000 \times 337) \]

\[ \text{MAP} = 21,237 \text{ kg (46,722 lb)} \]