Application of Genetics in Aquaculture and Fisheries Practices

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Main Genetic Parameters
phenotype and genotype

• **Phenotype** of an individual is how an individual looks = appearance

• This phenotype could be qualitative or quantitative

• **Genotype** is the genetic make up of an individual

• Improving a phenotype is done through working on a hidden element (genetic make up of an individual G).
Qualitative traits

• Qualitative genetics is known after Mendel (Mendelian genetics)
• Qualitative traits have a distinct appearance (phenotype): either this or that; individuals can be placed in one of few discrete classes
• Each trait is controlled by one gene in most situations
• Inherited disease or colorations are examples
• These traits are not influenced by environmental conditions
• Selection for qualitative traits are designed to fix desired alleles and eliminate undesired alleles
• With some exceptions, qualitative traits are less important in aquaculture
Qualitative traits in:

Aquaculture

Red tilapia for Sushi dishes – frequently marketed under red snapper

Non-aquaculture systems

When shape and coloration are far important than weight or FCR
Quantitative traits

• Most productive traits are quantitative (weight, length, FCR, fecundity,...)

• Quantitative phenotypes in a population exhibit continuous distributions

• Controlled by several genes and environment influences the phenotype: \( P = G + E + G-E \)

• In order to improve phenotype traits, their variance should be analyzed and sorted into heritable and non-heritable components

• Heritable component is what breeders are interested in
Quantitative phenotype

Normal distribution
Phenotypic and genotypic variance

• There should be a variance in order to attain some improvements through genetics

• If all individual are identical and look the same, there will not be a real chance for their improvement

• Phenotypic variance ($V_p$) is the sum of: genetic variance ($V_G$), environmental variance ($V_E$), and the variance resulting from genetic-environmental interaction ($V_{G-E}$)

$$V_P = V_G + V_E + V_{G-E}$$
Environment Variance ($V_E$)

• $V_E$ has no genetic basis. This means that a phenotype if related environment could improve regardless the genetic make up of such organism. Fish will perform better if are farmed under optimum growing conditions compared to marginal growing conditions.

• If $V_E$ is neither controlled nor quantified or got confound with $V_G$, it will not be possible to evaluate the genetic improvement and this can ruin a breeding program.

• $V_E$ is not transmitted from parents to offspring
Environmental variance (examples)

**Shooting:** This phenomenon was found in common carp, *Cyprinus carpio*. It is defined as the sudden and dramatic growth of the shoot individuals (shooters; jumpers). Shooting occurs when fry began to feed on natural food. Also, the particle size of the feed had a marked effect on shooting. The degree of food availability was found to have an effect on shooting as well. Competition for food/space has been identified as the cause of shooting. If shooters are selected as broodstock, no progress should be expected.
Environmental variance (examples- Cont.)

- **Egg size (Maternal effect):** This occurs when a pronounced effect is found of egg size on the growth rate of early life of fish and when this effect disappears as fish gets older. In Nile tilapia, the effect was virtually gone by 20 days. Thus, selection should not be carried out before such effect disappears.

  - Because egg size could be influenced by environmental factors as well as genetics, it is crucial to use females of same age and comparable size, otherwise, detected differences in their progeny may be due to mother's age, size, or diet, and not to genetic makeup.
Genetic variance $V_G$

$$V_G = V_A + V_D + V_I$$

- $V_A$ additive (utilized by selection)
- $V_D$ dominance (utilized by hybridization)

$$h^2 = \frac{V_A}{V_P} \text{ (runs from 0-1)}$$

The value of Heritability coefficient ($h^2$) indicates how genetics is affecting the phenotype.
Heritability and breeding programs

Phenotypes with $h^2 \geq 0.25$ can be changed effectively through selection (e.g. mass selection)

Phenotypes with $h^2 \leq 0.15$ breeders may choose family selection or adopt a different breeding program (e.g. hybridization)

However, adding few grams to the weight through selection will be less important compared to adding 1-2 degree centigrade to low temperature tolerance for a species
“Realized Heritability” and selection

Response to selection $R = \text{Heritability } h^2 \times \text{Selection Differential } D$

Levels of selection differential is related to selection intensity – This can go up to a limit otherwise genetic problems may develop (e.g. inbreeding)

When a population shows a sexual dimorphism, separate curves for males and females should be constructed
Inbreeding

• Inbreeding is the mating of relatives. Related individuals may share alleles (genes) through one or more common ancestors

• If the harmful & recessive genes that are hidden in the heterozygous state are expressed through the mating of relatives, they will produce abnormal or lethal phenotypes which are known by “inbreeding depression” as expressed in deformity, poor performance, and could lead to mortality

• Smaller mating population will result in higher possibility of inbreeding problems

• Inbreeding and Effective Breeding Number – will follow
Genetic management of broodstock

Effective Breeding Number ($N_e$)

- $N_e$ is the best term describing the population size (from genetics point of view). Since population of fish is finite, it is better to describe it by $N_e$ rather than absolute number.

- Effective breeding number depends on other factors such as number of breeding individuals, sex ratio and mating system (random; pedigreed)

\[
N_e = \frac{4(# \text{ females}) (# \text{ males})}{# \text{ females} + # \text{ males}}
\]

In random mating
Effective Breeding Number ($N_e$)

Why important?

Tendency to keep less males due to:

- Females **and not** males are the spawners.
- Males compete with females for space/feed.
- Males can mate with many females. Why keep more?

When value of numbers are not the absolute numbers?

**Genetic value of 100**

Real Fish

50 M + 50 F = 100  OR
31 M + 130 F = 161  OR
27 M + 340 F = 367

Genetic value of **10 M + 90 F = Only 36**
Genetic Management of Broodstock (2)
Enhancing Effective Breeding Number

Done through:

• Increase number of mating populations
• Bring the sex ratio as close as possible to 1:1
• Shift to pedigreed mating whenever possible

When you move fish: large number of fingerlings is much safer than smaller number of larger fish
Genetic consideration in broodstock management

- Wild sources of hatchery broodstock:
  - For first time ever
  - For stock enhancement programs
  - For species which cannot mature in captivity
  - Others

- From other hatchery/farm
  - Proven efficiency under particular environments (GxE)
  - Not passing through genetic bottlenecks (Brazil to USA)
  - From maximum number of spawns
Genetic-environment interaction

Does Exist **When**: Various genotypes perform differently in different environments

**Stocking density** – Feeding regime – **Salinity**

If compared genotypes maintained their rank in various environments

**No Interaction**

**Example**: Common carp strains (Chinese and Polish) in:
- Different stocking densities
- Different feeding regimes (fertilization and artificial feed)
| Strain   | Environment A | Environment B | Interaction  
|---------|---------------|---------------|-------------
| Strain A| 80            | 60            | No interaction |
| Strain B| 60            | 40            | Mild interaction |
| Strain A| 80            | 60            | Strong interaction |
| Strain B| 60            | 50            |              |
| Strain B| 60            | 70            |              |
Genetic enhancement approaches

**Traditional Approaches**

- Selection
- Hybridization

**Advanced approaches**

- Ploidy induction
- Genogensis - Anderogensis
- Genetic engineering
Selection – Selective breeding

• The oldest approach for genetic improvement
• It is simply a choosing the parents of coming generations (positive selection) and what to cull (negative selection)
• As long as $V_A$ exists, progress due to selection accumulates over generations.
• Selection plateau is reached when genetic variation $V_A$ is consumed – No more progress. In such as external interventions will be needed to create variations (e.g. mutation)
Selection (Selective breeding)

Choosing the “best” individuals as breeders

G₀ → G₁ → G₂ → G₃

“Bad genes”
“Useful genes”
Selection - moving the mean

$G_n$

$G_{n+1}$
Selection strategies

Individual (mass) Selection: Choose the best
• When $h^2$ for selected traits is high
• Easy to conduct (methodology, facilities and recording)
• Requires high heritability
• For traits of live organism

Family Selection (select or reject the whole family)
• When $h^2$ for selected traits is lower
• Require more tagging & recording
• A must for traits such as meat quality & dressing percentage

Within Family selection
• Keeps the best of each family
Multiple trait selection

Tandem selection
• One trait at a time
• Correlation between trait is an issue (especially negative)
• Require long time

The more the traits are, the most difficult will be the program

Independent culling
• May restrict the size of selected population (depending on the cut-off value)
• Possible loose of superior individuals in a trait regardless!!
• Some modification was felt needed
Multiple Trait Selection
Independent Culling

Only individuals with 1.5 kg and above and with head : body of 1.5% and less are kept.
Relaxing the cut-off value for a trait has saved superior individuals for the second trait. Example: an individual of 1.3 kg is selected due to its better dressing percentage.
Multiple trait selection

Selection index

• Economic in terms of time, money and effort, to perform selection on several characters simultaneously
• Reflect better the industry requirement (tilapia: growth, cold tolerance/late maturation; shrimp: growth, disease resistance)
• Has been applied to key finfish (e.g. Atlantic salmon)
• Currently applied for Pacific white shrimp, *Litopenaeus vannamei*

Relative importance of traits varies among species
Species purity and hybridization barriers:

- Purity of species in nature is maintained: hybridization barriers
- Some of hybridization barriers could be managed in hatcheries (e.g. seasonality)
- Unmanaged barriers (chromosomal no.)

Hybridization could be:

- Intergeneric (among genera)
- Interspecific (among species)
- Intraspecific (strains within species- cross breeding)
Traditional approaches

Hybridization

Carried out for:

**Hybrid Vigor:** The tendency of hybrids to grow faster, get larger, tolerance more to specific conditions, or better dressing than their parents. Also called heterosis.

**Examples:**
- grass carp x silver carp
- silver carp x bighead carp
- common carp x bighead carp

Production of uniform progeny
Traditional approaches

Hybridization

**All-male production – all-female production:** Sexual maturation causes aggressiveness and reduce growth. This may favor one sex over other. In rainbow trout, all-female production is almost universally used in Europe as females are still immature at harvest. **In tilapia,** all-male production is preferred because of higher growth rate and to avoid unwanted reproduction.

**Sterility: Examples:**

- grass carp x bighead carp
- silver carp x common carp

**Note:** some hybrids are fertile; e.g. tilapia – Indian carps
Interspecific hybridization (e.g. tilapia)

• Two species of tilapia can be crossed to yield all-male offspring.

• Male Hornorum or aureus tilapia can be hybridized with the female of Nile tilapia to produce all-male offspring (theoretically).

• Tilapia hybrid is **fertile** and can backcross with parent species which could **upset** the purity of parent species (Nile tilapia in Lake Victoria).
Hybridization

Male Hornorum/aureus

ZZ

XX

Nile tilapia female

XZ

All-male hybrid tilapia

Why not 100?
Hatchery Broodstock

• Hybrids which could be excellent for grow-out cannot be broodstock

• For species purity, if hybridization is carried out in a hatchery, hybrids should be kept in isolate
Advanced genetic technologies
Ploidy induction

Triploidy production (3 n):
sterility (grass carp)
environmental reasons (reduced risk of escapees)
higher growth rate (possibility bigger cell size)

Tetraploidy production (4 n):
a step towards triploidy production

Shocks are used (temperature, cold, pressure, chemicals). Timing varies
Triploidy induction

Shocks are performed through:
- Heat
- Cold
- Pressure
- Chemicals
Tetraploidy production

Egg 1 N × 2 N

Chromosomes duplicate

Polar body falls

Shock to prevent 4-N cell division
More chromosomal manipulation

YY tilapia super male

• Sex chromosome of Nile tilapia is (XX) for female and (XY) for male
• Normal mating produces 50% of each sex
• Using estrogen for 28 days during the larval phase, will end by phenotypic all-female fry
• 50% of these “feminized fry” are genetic females (XX) and 50% are genetic males (XY)

XX females are identified and discarded

• Reversed females (XY) when individually paired with normal males (XY), 25% of offspring will be super male (YY)
More chromosomal manipulation

YY tilapia super male

Progeny testing is required (**squash technique**) to identify genetic make-ups of females.
Advanced genetic technologies

Gynogensis:
Used for the production of off springs having its genetic make-up from mother upon the use of irradiated sperm using UV which destroy its DNA.

Androgensis:
Used for the production of off springs having its genetic make-up from father upon the fertilization of irradiated ova using UV which destroy its DNA by normal sperm.

Both approaches are used to produce highly inbred lines as required by some breeding programs

*The Boys from Brazil* (1978)
Genetics in movies and imaginations

Androgensis

Sara Bernhardt: Imagine we had a child, and it had my looks and your brain

Hybridization

George Bernard Shaw: Yes, but imagine if it had your brain and my looks
Advanced genetic technologies

Genetic engineering (gene transfer)

Fish are ideal organisms for genetic engineering programs because of:

• High fecundity
• Short generation (utilized for other purposes)
• External fertilization
• Large size ova
Genetic Engineering

**Gene transfer**

**Phases of application**
- Successful insertion of the gene
- Expressing the transferred gene
- Heritability of traits

**Concerns:**
- Will remain at experimental stage for some time
- Significant opposition
- Biosafety is a must for experimentation
Genetics in:
Stock Enhancement Programs

Facts:

• There are substantial genetic differences between hatchery produced stock and the wild population of the same species

• Thus; Fish seed produced for aquaculture and for enhancement programs are not genetically the same

• Genetically improved seed for aquaculture are normally adopted to the farming environment and selected for production traits which may represent a threat to the fitness of wild stocks.
Predator avoidance could be a top important trait to wild stocks while has no value to aquaculture stocks.

Noticeable problems may result from the mating of hatchery produced stocks with their wild counterparts.

Some international stock enhancement programs designate special hatcheries for stock enhancement (managed differently).

To reduce the possibility of domestication, seed produced in hatcheries should not be grown out for use as broodstock. Rather, broodstock should be taken from wild stock to maintain genetic diversity.
Away from genetics in:
Stock Enhancement Programs

• Conflicting opinions
• Some large programs have closed
• Unless managed properly & outcomes are validated, it will remain debatable
• Management is better than overfishing then restocking
Conclusion

• The possibility of enhancing fish production through management has delayed the utilization of genetics due to cost and time required & difficulty impression

• As aquaculture develops and challenges continue, it became obvious that husbandry practices have limits especially with issues of genetic nature (e.g. cold tolerance)

• Artificial propagation in hatcheries is a main step towards the application of genetics in aquaculture

• Fish genetics programs is the responsibility of research institutes, while mass production takes place in hatcheries

• What is seen fancy in the present could be in application in the near future
Thanks for your time. I hope you have found in this presentation some of what you were looking for

While welcoming you to use the contents of this presentation, thanks in advance for referring to it

If you have any comment about this presentation or you need clarification or elaboration, I would welcome your contact via my email address