Ph.D. (FISH GENETICS AND BREEDING)

Course Structure and Credit distribution

A	**Major Courses**		**Credit**	**12 Credits**
1	**FGB 601**	**DESIGN OF BREEDING PROGRAMS**	2+1	
2	**FGB 602**	**GENETIC SELECTION OF COMPLEX TRAITS**	2+1	
3	**FGB 603**	**FISH GENOME AND GENOMIC SELECTION**	2+1	
4	**FGB 604**	**LINEAR MODELS AND EXPERIMENTAL DESIGNS IN FISH GENETICS**	1+2	
B	**Minor Courses** (From the subjects closely related to a student's major subject)			**6 Credits**
C		**Supporting courses** (The subject not related to the major subject. It could be any subject considered relevant for students research work (such as Statistical Methods, Design of Experiments etc.) or necessary for building his/her overall competence).		**5 credits**
		Total Course Work Credits		**23 credits**
D	**DOCTORAL SEMINAR**			**2 credits**
	FGB 691	Doctoral Seminar	0+1	
	FGB 691	Doctoral Seminar	0+1	
E	**DOCTORAL RESEARCH**			**75 credits**
1	FGB 699	Doctoral Research (Semester II)	0+15	
2	FGB 699	Doctoral Research (Semester III)	0+15	
3	FGB 699	Doctoral Research (Semester IV)	0+15	
4	FGB 699	Doctoral Research (Semester V)	0+15	
5	FGB 699	Doctoral Research (Semester VI)	0+15	
		Total PhD Program Credit Hours		**100 Credits**

FGB 601 DESIGN OF BREEDING PROGRAMS (2+1)

Objective	**To learn the recent advances and development of breeding plans**
Theory	
Unit-I	Genetics in Broodstock management of commercially important fish and shellfish Assembling base population, Choosing selection objectives and criterion Pedigree identification-Physical & molecular tagging; maintaining breeding records
Unit-II	Genetic parameters- heritability, repeatability, Genetic, Phenotypic and Environmental correlations Factors influencing genetic progress Comparison of Selection Systems- Criteria and procedure for comparison, Long term program, Short term program, Single population program; Open Nucleus Breeding System (ONBS) Case study of national and international genetic improvement programs viz., JayantiRohu, *Clariasmagur*, GIFT Tilapia, Norwegian Salmon, Pacific White Shrimp *L.vannamei*and others
Unit-III	Important reproductive tools for implementation of breeding plan: Captive maturation, Synchronization of spawning Cryopreservation of gametes Application of Hybridization, ploidy manipulation, monosex culture, genetic engineering, transgenesis for commercial purpose
Unit-IV	Designing mating plans Inbreeding, Types of inbreeding, Genetic and Phenotypic effect of Inbreeding; Consequences of inbreeding and management of genetic variation in fish breeding program Genetic selection and its impact on natural stock Outbreeding, Forms of outbreeding, effects of outbreeding Breeding plans to exploit additive and non-additive genetic variation Maternal influence and its estimation Genetic mechanisms in adaptation, measurement and adaptability indices G x E interaction.
Unit-V	Breeding plans for shellfish improvement, controlled mating in shellfish Developing new ornamental strains of fishes: Inheritance of ornamentation traits; Sex linked inheritance of ornamentation; recording ornamentation traits; molecular genetics of body pigmentation
Unit-VI	Genetics of developing SPR strain: Immune system in fish and shell fish and genetics of immune system Genetics of disease susceptibility; application of genetic tools to predict disease susceptibility; developing plans for genetic selection of threshold traits

	Fish genetics and welfare: A continued need for genetic selection scientific, regulatory and public acceptance issues Ethical, moral and fish welfare issues Ownership of genetically improved strain through public sector funding
Practical	
	Developing Growth curves and their components Estimation of Genetic Parameters; Selection and genetic gains Path coefficient and calculation of inbreeding coefficient and relationship Designing breeding programs for threshold traits, Estimation of heritability of threshold traits Preservation of gametes; Synchronization of spawning; Developing the protocols for evaluating the various genetic improvement programs and their impacts Survey on impact of the program on farmers and consumers Impact of climate change on fish germplasm The focus will be on critical review of contemporary applied breeding programs and journal articles - students are also expected to prepare a term paper for submission at the end of the semester
Suggested Readings	1. Doolittle DP. 1987. *Population Genetics: Basic Principles*. Springer-Verlag. 2. Falconer DS &Markay TFC. 1996. *An Introduction to Quantitative Genetics*. 4th Ed. Addison Wesley Longman. 3. Pirchner F. 1983. *Population Genetics in Animal Breeding*. Plenum Press. 4. Thomas PC, Rath SC &Mohapatra KD. 2003. *Breeding and Seed Production of Finfish and Shellfish*. Daya Publ. House. 5. Gjedrem, Trygve et al., 2005. Selection and Breeding Programs in Aquaculture Springer 6. https://www.wur.nl/upload_mm/d/b/b/614bcc19-036f-434e-9d40-609364ab26da_Textbook%20Animal%20Breeding%20and%20Genetics-v17-20151122_1057.pdf Suggested Journals: Aquaculture, Aquaculture Reports, Aquaculture Research, *Genetics,* Indian Journal of Fisheries, Journal of Fish Biology The Journal of heredity

FGB 602 GENETIC SELECTION OF COMPLEX TRAITS (2+1)

Objective	**To impart knowledge on the efficiency of different selection methods**
Theory	
Unit-I	Introduction: Past and present status of fish breeding Complex traits and their inheritance Recording complex traits
Unit-II	Strain comparison Factors affecting the rate of genetic improvement

	Performance testing; Estimation of genetic gain under different selection program
Unit-III	Influence of non-genetic factors on growth Factors influencing production and reproductive traits Correction and standardization of animal breeding data Simultaneous prediction of breeding values for several traits Recurrent and Reciprocal Recurrent Selection Crossbreeding and hybridization;
Unit-IV	QTL and MAS; Breeding values for binary traits Threshold characters and their selection procedure Selection and breeding for disease resistance and survival analysis Diallel analysis; Selection for single trait and multiple traits
Unit-V	Organizing breeding programs-Structure of breeding programs, Breeding for optimum production, economic value of each animal, cost of broodstock production, organizing field trial Farmers cooperatives-breeding companies, National or local breeding programs
Unit-VI	Dissemination procedures and issues, Breeding nucleus, multiplier centers Socio-economic impact, technological adoption, increased production Economic Evaluation of Genetic Breeding Programs-Criteria for Economic Evaluation: Profit Horizon, Interest Rate, and Return on Investment Environmental impact of improved varieties/strains
Practical	
	Application of various computer software for genetic analyses: SAS, R, AsReml etc. Application of Mixed models for estimation of genetic parameters-Heritability, Correlations; Estimation of breeding values EBV, BLUE, BLUP Construction of selection index Diallele crossing Developing and evaluating the dissemination programs of genetically improved strain QTL parameter estimation; Analysis of QTL as random effect
Suggested Readings	1. Cameron ND. 1997. *Selection Indices and Prediction of Genetic Merit in Animal Breeding*. CABI. 2. Morde 3. Gjedrem, Trygve et al., 2005. Selection and Breeding Programs in Aquaculture Springer 4. Falconer DS &Markay TFC. 1996. *An Introduction to Quantitative Genetics*. 4th Ed. Addison Wesley Longman. 5. Lynch M & Walsh B. 1997. *Genetics and Analysis of Quantitative Traits*. Sinauer, Sunderland.

	6. Joel Ira Weller.2016. Genomic Selection in Animals. John Wiley & Sons, Inc., New Jersey. 7. Isik, Fikret, James Holland, and Christian Maltecca.2017. Genetic data analysis for plant and animal breeding. New York: Springer. 8. https://www.wur.nl/upload_mm/d/b/b/614bcc19-036f-434e-9d40-609364ab26da_Textbook%20Animal%20Breeding%20and%20Genetics-v17-20151122_1057.pdf 9. https://www.jmp.com/en_us/academic/jmpg-course-materials.html Suggested Journals: Aquaculture, Aquaculture Reports, Aquaculture Research, *Genetics,* Indian Journal of Fisheries, Journal of Fish Biology The Journal of heredity

FGB 603 FISH GENOME AND GENOMICSELECTION (2+1)

Objective	**To impart knowledge on understanding genomes, application of genomic tools and strategies for enhancing production performances and conservation of fish genetic resources**
Theory	
Unit-I	Organisation of genomes : Genome, Genomics, Transcriptomics, and Proteomics Genome size estimation, Genome size in model organisms, C- value paradox, Genome diversity Taxonomy and significance of genomes, Classification of genomics, Vertebrate genome evolution Establishing phylogeny on the basis of genomics, Comparative genomics, population genomics Limitation and application of genomics Structural genomics: Linkage maps and QTL, Haplotype structure of genome; Genetic, physical and transcription maps, Fluorescent in situ hybridisation, Radiation hybrid mapping, Sequence tagged site mapping, Restriction mapping.
Unit-II	Functional genomics: NGS data analysis, sequence assembly, gene identification, Gene prediction rules, Gene annotation and pathway analysis genome databases and browsers, , Gene ontology assignment, mining of transcriptome data for protein coding genes, differentially expressed genes, short and long non coding RNA and their target genes. Next generation sequencing: Second and third generation sequencing platforms NGS platforms such as Illumina, Roche 454, SOLiD, Ion torrent, PacBio, Oxford Nanopore Technologies, principles, applications and limitations
Unit-III	Genome projects: The human genome project, HapMap project, The 100 genome project, Encode project Ethical, legal and social issues of human genome project;

	Fish genome projects: Fugu, Tetraodon, Elephant shark, Atlantic salmon, Zebra fish, Common carp, Rainbow trout, Channel catfish, Fishes in Genome 10 K project, status of fish genomics research in India IPR issues; Patent at one place and not in another Access to fish genetic resources
Unit-IV	Genomic tools: Genome wide association studies, Custom microarray technologies, DNA microarray, SNP array, Subtractive hybridization, comparative genomic hybridization
Unit-V	Application of markers in fish breeding, Genomic resources: ESTs, RFLPs, Microsatellite markers, SNPs, BAC library Molecular pedigree assigning, Molecular-kinship estimation, Experimental designs to detect QTL, generation of linkage disequilibrium Limits to response via MAS; Implementing MAS in breeding programs
Unit-VI	GENOMIC SELECTION- Overview of Implementation and Benefits of Genomic Selection Genomic Best Linear Unbiased Prediction (GBLUP); Two Equivalent Mixed Models for GBLUP of Breeding Values; GBLUP for Individuals without Phenotypic Observations Genomic Estimation of Variance Components; Genomic Estimation of Heritabilities; Genomic Relationship and Correlation
Practical	
	Tools for NGS data analysis QTL Analysis, Hapalotype based QTL analysis Genomic approaches to selection for disease resistance Genomic tools: Genome wide association studies, custom microarray technologies, DNA microarray, SNP array, Subtractive hybridization comparative genomic hybridization Estimation of GBLUP; Genomic Estimation of Variance Components; Genomic Estimation of Heritabilities; Genomic Relationship and Correlation
Suggested Readings	1. Brown T.A. (2017) Genomes 4 (4th edition). Garland Science, US, 544 pp. 2. Dunham I. 2003. Genome mapping and sequencing, Panima Publishing Corporation-New Delhi, 470 pp. 3. Primrose S.B. &Twyman R.M., (2006) Principles of Gene Manipulation and Genomics (7th edition). Blackwell Publishing, Oxford UK., 672 pp. 4. Hartwell, L.H., Hood,H.L., Goldberg, M..L, Reynolds, A.E., Silve L.M. and Veres R.G. 2004. Genetics: From Genes to Genomes McGraw-Hill Education. 5. Primrose S.B. and Twyman R. M., .2006. Principles of gene manipulation and genomics. 6. Sahai S. 2002. Genomics and Proteomics, Functional and Computational Aspects, Kluwer Academic Publishers, New York. 7. Joel Ira Weller.2016. Genomic Selection in Animals. John Wiley & Sons, Inc., New Jersey

	8. David Siegmund and Benjamin Yakir.,2007.The statistics of Gene Mapping. Springer, USA. 9. Isik, Fikret, James Holland, and Christian Maltecca.2017. Genetic data analysis for plant and animal breeding. New York: Springer. 10. https://www.wur.nl/upload_mm/d/b/b/614bcc19-036f-434e-9d40-609364ab26da_Textbook%20Animal%20Breeding%20and%20Genetics-v17-20151122_1057.pdf 11. https://www.jmp.com/en_us/academic/jmpg-course-materials.html Suggested Journals: Aquaculture, Aquaculture Reports, Aquaculture Research, *Genetics,* Indian Journal of Fisheries, Journal of Fish Biology The Journal of heredity

FGB 604 LINEAR MODELS AND EXPERIMENTAL DESIGNS IN FISH GENETICS (1+2)

Objective	**To learn the application of different statistical models in breeding data.**
Theory	
Unit-I	The Binomial, Poisson, Normal models; ANOVA, Multiple regression and correlation Testing of genetic hypothesis, test of hypothesis, Hierarchical classification- Variance Components Linear Mixed Models (LMMs) an overview Clustered data, repeated measures, Longitudinal data; Levels of Data; Types of factors and their related effects in LMM- Fixed effects, Random effects
Unit-II	Matrix operations: Determinants, inverse of matrix, linear equations, the matrix algebra of regression analysis.
Unit-III	Specification of LMM: General specification for an individual observation General matrix specification-Covariance structure for the D and R matrix Mixed models: Predicting Random effects- Best Linear Unbiased Predictors (BLUP), their application in estimation of genetic variance components and parameters BLUP Under the Animal Model; BLUP with Repeated Records; Analysis of non-orthogonal and multivariate data.
Unit-IV	Maximum likelihood (ML) estimation of variance-covariance components- Structure of Variance-Covariance Matrix as a Function of Partial Derivatives ML Estimation of Variance-Covariance Components Restricted maximum likelihood estimation (REML) of Variance-covariance components- General REML Equations; REML Using the CE and the MME methods of BLUP
Unit-V	AMOVA Challenge Test-Designing the challenge tests, Data collection protocols

Unit-VI	Model building and simulations; simulation of phenotypes; simulation of fish breeding in different conditions
Practical	
	Matrix operation, matrix inversion, matrix algebra of regression analysis Least Squares analysis in one way classification Use of various statistical packages for genetic parameter estimations: SAS, R, AsReml, PEST, SelAction One way classification with regression and covariance Two way classification with and without interactions Multiple and nested classification Predicting Random effects- Best Linear Unbiased Predictors (BLUP) Maximum likelihood estimation of genetic parameters, Analysis of non-orthogonal and multivariate data; Genomic Best Linear Unbiased Prediction (GBLUP) Genomic Estimation of Variance Components Genomic Estimation of Heritability Survival analysis- commonly used survival functions, Kaplan-Meier estimate of survival function, Cox regression method, Hazard ratio and survival
Suggested Readings	1. Dutkowski G & Gilmour A. 2005. *AsReml Cook Book*. Statistical Software Package. 2. Littell RC, Milliken GA, Stroup WW &Wolfinger RD**.** 1996. *SAS Systemfor Mixed Models*. SAS Institute. 3. Lynch M & Walsh B. 1997. Genetics and Analysis of Quantitative Traits. Sinauer, Sunderland. 4. Saxton AM. 2004. *Genetic Analysis of Complex Traits Using SAS*. SAS Publ. 5. West B.T. Welch, K.B. and Gatecki, A.T. 2015. Linear Mixed Models. CRC press 6. Isik, Fikret, James Holland, and Christian Maltecca.2017. Genetic data analysis for plant and animal breeding. New York: Springer. 7. Kruschke J.K. 2015. Doing bayesian data analysis. Second Edition. Academic Press 8. https://www.wur.nl/upload_mm/d/b/b/614bcc19-036f-434e-9d40-609364ab26da_Textbook%20Animal%20Breeding%20and%20Genetics-v17-20151122_1057.pdf 9. https://www.jmp.com/en_us/academic/jmpg-course-materials.html Suggested Journals: Aquaculture, Aquaculture Reports, Aquaculture Research, *Genetics,* Indian Journal of Fisheries, Journal of Fish Biology The Journal of heredity

List of Suggested Journals

- ActaCytologica
- Advances in Genetics Incorporating Molecular Genetic Medicine
- Animal Genetic Resource Information

- Animal Genetics
- Annual Review of Genetics
- Bioinformatics
- Biological Conservation
- BMC Bioinformatics
- BMC Molecular Biology
- Breeding Science
- Briefings in Bioinformatics
- Briefings in Functional Genomics and Proteomics
- Cancer Genetics and Cytogenetics
- Conservation Biology
- Conservation Genetics
- Cytogenetics
- In Silico Biology
- Indian Journal of Agricultural Statistics
- Indian Journal of Cytology and Genetics
- Indian Journal of Genetics and Plant Breeding
- Indian Journal of Statistics
- Journal of Animal Breed and Genetics
- Journal of Animal Science
- Journal of Applied Statistics
- Journal of Bio-Chemistry and Molecular Biology
- Journal of Computational and Graphical Statistics
- Journal of Genetics
- Journal of Heredity
- Journal of Molecular Biology
- Journal of Official Statistics
- Journal of Statistical Software
- Journal of Statistics Education
- Journal of Tissue Culture Methods
- Molecular Cytogenetics
- Molecular and Cellular Biology

List of Suggested e-Resources

- http://www.ncbi.nlm.nih.gov/
- http://www.genome.gov
- http://www.hgsc.bcm.tmc.edu/projects/bovine
- http://www.animalgenome.org
- http://www.blackwell-synergy.com
- http://www.genomics.liv.ac.uk
- http://www.biomedcentral.com
- http://www.genomealliance.org.au
- http://www.csiro.au
- http://www.isag.org.uk
- http://www.ebi.ac.uk/imgt/
- http://www.csrees.usda.gov

Suggested Broad Areas for Master's and Doctoral Research

- Cryopreservation of gametes of species of commercial importance
- Estimation of gene and genotype frequencies using various population genetic tools (markers)
- Estimation of effective population size, inbreeding accumulation rate in a breeding population
- Genetic stock structure analysis; genetic variability studies of species o commercial importance
- Estimation of genetic parameters in species of commercial importance
- Developing breeding plans for different commercial fish and prawn species
- Estimation of genetic parameters in species of commercial importance
- Estimation of heterosis and Inbreeding depression in breeding population
- Construction of growth curves for different commercial fish and prawn species Developing breeding plans for different commercial fish and prawn species
- Cryopreservation of gametes of species of commercial importance
- Application of molecular genetic markers for estimation of effective population size, rate of inbreeding
- Estimation of genetic diversity and relatedness using molecular information
- Morphometric analysis of stocks
- Milt quality analysis and cryopreservation of milt
- Estimation of linkage disequilibrium using molecular genetic data
- Application of molecular genetic markers for estimation of

effective population size, rate of inbreeding

- Estimation of genetic diversity and relatedness using molecular information
- QTL Analysis and application in selective breeding
- Estimation of linkage disequilibrium using molecular genetic data
- Application of molecular genetic markers for estimation of effective population
- size, rate of inbreeding
- Estimation of genetic diversity and relatedness using molecular information
- QTL Analysis and application in selective breeding
- Chromosome mapping for different commercial fish and prawn species
- Karyotyping and chromosome spread preparation for different commercial fish and prawn species
- Estimation of genetic parameters using various statistical packages like SAS, AsREML, PEST
- Molecular data analysis using softwares like GENEPOP
- Establishing cell lines
- Construction of growth curves for different commercial fish and prawn species
- Estimation of genetic and non-genetic parameters
- Developing breeding plans for different commercial fish and prawn species
- Cryopreservation of gametes of species of commercial importance
- Developing breeding plans for different commercial fish and prawn species
- Estimation of genetic parameters in species of commercial importance
- Estimation of genotype-environment Interaction
- Estimation of heterosis and Inbreeding depression in breeding population
- Socio-economic impact studies for genetically improved varieties
- Evaluation of International genetic improvement programmes
- Chromosome mapping for different commercial fish and prawn species
- Karyotyping and chromosome spread preparation for different commercial fish and prawn species
- Pedigree assigning using molecular data
- Estimation of genetic parameters using molecular data
- Estimation of genetic and non-genetic parameters using various statistical packageslike SAS, AsREML, PEST