

Modelling Floodplain River Fisheries – an Introduction

Training Workshop Materials

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Background

This presentation is one of a series of five presenting key outputs from FMSP floodplain projects, carried out in the Asian region between 1992 and 2005. The five papers focus on:

- General management guidelines for floodplain river fisheries (as published in FAO Fisheries Technical Paper 384/1)
- Selection and management of harvest reserves (key messages)
- Materials for a training course on harvest reserves
- Flood Control Impacts on Fisheries: Guidelines for Mitigation
- **Modelling floodplain river fisheries**

This presentation was prepared by FMSP Project R8486 – 'Promotion of FMSP guidelines for floodplain fisheries management and sluice gate control'

Introduction

The following materials are provided for adaptation or use in workshops aimed at building awareness of the range of models and approaches that can be used to guide the management of floodplain-river fisheries resources.

The models and approaches described here were either developed or applied under research projects funded under the Fisheries Management Science Programme of the UK Government's Department for International Development (DfID).

Further details of the empirical models and methodologies described here can be found in Section 14 of Hoggarth et al (in press) which may be provided as a handout.

Other relevant papers, reports and sources of information are provided under each section.

Full references and URLs are provided at the end of this presentation.

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Introduction

What are models?

Models are quantitative descriptions of processes or relationships among variables.

Types of Model

In the context of fisheries management, models can be divided into 2 main categories:

Empirical Models. These are simply statistical descriptions of the observed relationships among two or more variables of interest.

Population dynamics models. These attempt to explicitly model the dynamics of fish populations based upon established theories of population behaviour, and biological and ecological processes.

Introduction

Purpose of Models

- Models are used to make predictions about, or improve understanding of the response of important **dependent** variables to changes in **independent** variables.
- **Dependent** variables are often referred to as **response**, **output** or **performance** variables and typically include catch, indices of abundance, income...etc.
- **Independent** variables are often referred to as **input** or **explanatory** variables. Examples include fishing effort, stocking density, environmental variables (e.g. flood extent)...etc.

Further Reading: Haddon (2001).

Empirical Models: Simple Linear Models

- Simple empirical models are frequently used in floodplain river fisheries to describe the linear relationships between two variables of interest.
- They are typically fitted to estimates of annual catch and a variety of different explanatory variables (e.g. resource area, fishing effort, hydrological indices...etc) using linear regression methods.
- Variables are often first \log_e transformed to ensure that the normality assumptions behind the regression method are met.
- When few or no estimates of annual catch are available for a given fishery or management location, some estimate of potential yield may be obtained by comparing estimates reported for other river fisheries or management sites in relation to common explanatory variables such as resource area.

Empirical Models: Simple Linear Models

- Models based upon such *among fishery comparisons* can provide planners and policy makers with an **approximate** indication of the potential yield from the river fishery.
- Figure 1 illustrates the relationship between \log_e catch and floodplain area for Asian river systems reported by the DfID-funded Project R5030 (see MRAG 1993; 1994 and Halls 1999).

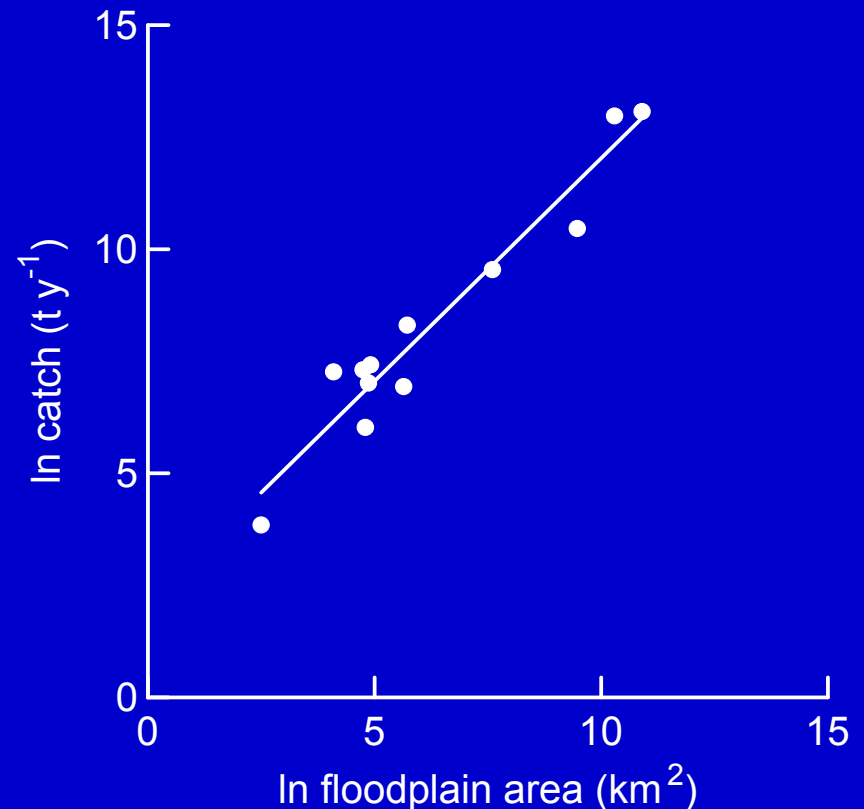


Figure 1. Potential yield from Asian floodplain rivers plotted as a function of floodplain area with fitted regression lines on loge transformed scales.

Empirical Models: Simple Linear Models

- Details of this and other best fitting models for predicting annual catches from tropical river fisheries developed under R5030 are summarised in Table 1 below, together with guidance for estimating 95% confidence intervals around the predictions.

Table 1 Summary of the best fitting regression models for predicting multispecies potential yield from floodplain-river systems where a and b are the constant and slope parameters of the linear regression model: $Y = a + bx$, and where n is the number of observations, R is the correlation coefficient, and P is the probability that the slope parameter, $b = 0$. S_b is the standard error of the estimate of the slope coefficient, b , $s^2_{Y.X}$ is the residual mean square, and \bar{X} is the mean value of the observations of the explanatory variable.

Relationship	Continent	a	b	S_b	n	\bar{X}	$s^2_{Y.X}$	R	P
In catch vs In FPA	Asia	2.086	0.996	0.083	13	4.31	0.531	0.97	<0.001
In catch vs In length	Asia	-14.88	3.234	0.585	5	8.06	0.680	0.96	0.01
In catch vs In DBA	S. America	-3.60	0.936	0.218	15	12.87	1.457	0.77	0.001

Empirical Models: Simple Linear Models

Prediction intervals for yield corresponding to new observations of X_i is given by:

$$\hat{Y}_{new} \pm t(1 - \alpha / 2; n - 2) \times s\{\hat{Y}_{new}\}$$

where $s\{\hat{Y}_{new}\}$ is the standard error of the estimate given by:

$$s\{\hat{Y}_{new}\} = \sqrt{s^2_{Y.X} \left(1 + \frac{1}{n}\right) + \frac{(X_i - \bar{X})^2}{\frac{s^2_{Y.X}}{(S_b)^2}}}$$

where $s^2_{Y.X}$ is the residual mean square (the variance of Y after taking into account the dependence of Y on X), and S_b is the standard error of the estimate of the slope coefficient, b (Zar 1984, p272-275).

Empirical Models: Simple Linear Models

Applications

- Generally speaking, these types of models provide only very **imprecise** predictions because of the significant measurement error associated with the potential yield estimates used to fit the models.
- Potential yields are often estimated using (i) the Generalised Fishery Development Model (GFDM) approach described by Grainger and Garcia (1996), (ii) as the average annual catch value, or worst (iii) from a single observation, all of which are subject to potentially significant measurement and estimation error (no account is taken of fishing effort).
- The utility of these models is therefore restricted to providing a rough indication of the likely potential of the fishery for policy and development planning purposes.
- Note that whilst the examples illustrated above are based upon comparisons across wide geographical scales, this modeling approach may be equally, if not more, relevant on a more **local scale**, particularly in the context of **adaptive co-management**. (see **Co-management guidelines presentation**)

Empirical Models: Simple Linear Models

Database Resource

- Estimates of potential yield for lakes and rivers, and a wide range of corresponding habitat variables (e.g. resource area, indices of primary productivity and hydrological variables) have been compiled by Project R5030 from the literature and entered into a "Lakes and Rivers Database". This database resource will shortly become available on a CD published by FAO (see Dooley et al. in press).

Other Models

- Welcomme (1985; 2001) contain other examples of linear empirical models for predicting fish yields and species richness in tropical river basins.

Empirical Models: Multiple Linear Regression (MLR)

- When the response of a variable (e.g. annual catch) to two or more independent variables (covariates) is of interest (e.g. floodplain area and annual rainfall), then multiple linear regression (MLR) methods would be applicable.
- When using MLR methods it is important to ensure that the explanatory variables included in the model are indeed independent to avoid spurious results (e.g. rainfall and flooded area are unlikely to be independent).
- It is generally recommend that you should have at least 10 to 20 times as many observations (cases, respondents) as you have variables, otherwise the estimates of the regression line are probably very unstable and unlikely to replicate if you were to repeat the study.
- Beware of automatic (forward and backward) stepwise fitting methods. It is often safer to employ a manual backward stepwise fit, starting with all the variables in the model and then dropping the least significant variables in turn. For unbalanced designs, it is often necessary to return dropped variables to the model to determine the effect of different combinations of variables.
- Further useful guidance on fitting MLRs can be found at <http://www.statsoft.com/textbook/stmulreg.html>

Empirical Models: General Linear Models (GLM)

- Sometimes researchers are interested in understanding the effects of both **factors** (categorical variables) and **covariates** (scale variable) on dependent variables such as catch or CPUE.
- This is often the case in the context of **adaptive or co-management** when opportunities frequently exist to compare the outcomes (performance) of local management activities among sites. These comparisons can generate **lessons of success and failure** which can be used to adapt management plans accordingly (see Halls et al 2002 and the accompanying co-management guidelines presentation).
- Examples of important factors of interest might include:
 - Community based management: Present (1), absent(0).
 - Management: Gear bans (1); closed seasons (2); reserves (3).
 - Extent of poaching: low (0); medium (1); high (2).
- Examples of covariates might include:
 - Fishing intensity
 - Ratios describing the morphological characteristics of waterbodies (eg dry season area: flood season area)
 - Indices of flooding extent and duration.

Empirical Models: General Linear Models (GLMs)

- In this case, the use of the **General Linear Models (GLM)** approach would be applicable.
- GLMs are similar to regression models but can deal with both factors (fixed and random) and covariates. The factor variables effectively divide the population into groups.
- Detailed guidelines for building interdisciplinary GLMs for small scale fisheries have been developed by R7834 (see Halls et al 2002 and Hoggarth et al. in press).
- These include examples of models fitted to data compiled from co-management projects worldwide, as well as guidance on identifying sampling units, important variables, data levels and cleaning, exploratory analysis, sample sizes, sensitivity analysis...etc.
- More general guidance on GLMs can be found in McCullagh & Nelder (1989).

Empirical Models: Non-linear models

- Non-linear models are fitted when relationship between two variables is not linear, or cannot be 'linearised' by means of data transformations.
- Typically, models are fitted using *non-linear least squares methods* or other more sophisticated methods e.g. maximum likelihood methods and Bayesian estimation.
- For example, Halls et al (2002) fitted a non-linear modified Fox surplus production model using non-linear least squares to estimates of catch per unit area (CPUA) and fisherman density assembled from a number of floodplain rivers to provide some estimate of fishing intensity corresponding to maximum yield. (see Figure 2).

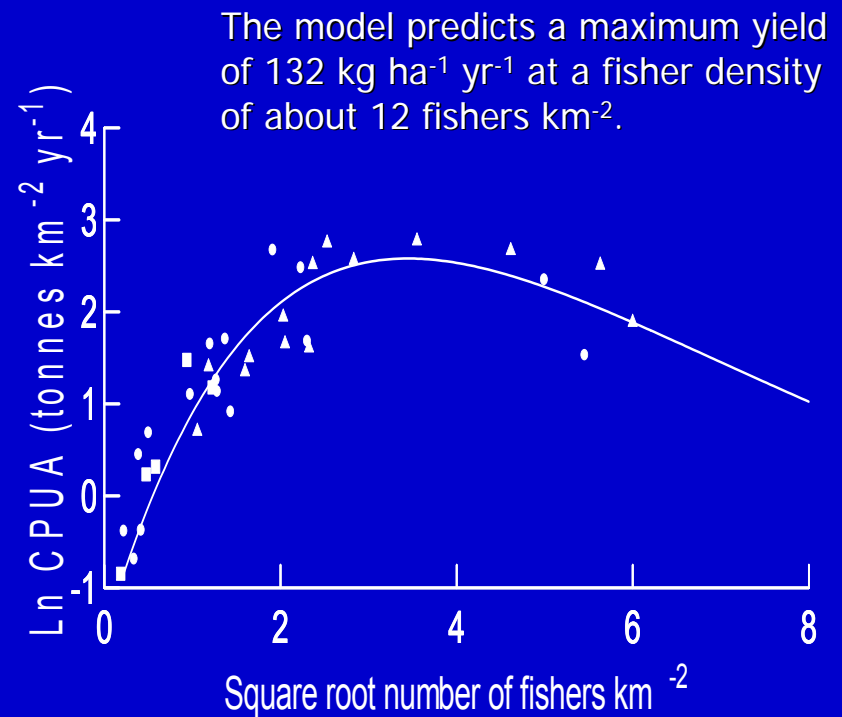


Figure 2 C.P.U.A vs. fisher density for floodplain rivers with fitted Fox model. Africa (•); Asia (▲); and South America (■). $R^2 = 0.80$. Note axis scaling. Source: Halls et al (2002)

Empirical Models: Non-linear models

- Further details of this and other related models can be found in Halls et al (2002) and Hoggarth et al (in press).
- Further advice on fitting non-linear models for fisheries applications may be found in Chapter 6 of Hilborn & Walters (1992) and Section 3.3 of Haddon (2001).

Empirical Models: : Bayesian networks (BNs)

- Unlike GLMs that deal with quantitative dependent (response) variables, **Bayesian networks (BNs)** provide opportunities to model more qualitative (categorical) response variables such as equity, compliance, empowerment etc.
- BNs comprise nodes (random variables) connected by directed links. Prior probabilities assigned to each link (established via tables of conditional probabilities) determine the status of each node.
- Conditional probabilities can be generated from cross-tabulations of the data *or* by using subjective probabilities encoded from expert opinions.
- BNs are able to model complex and intermediate pathways of causality in a very visual and interactive manner to improve understanding of co-management systems and fisher behavior.
- BNs can also be used as a management tool or expert system for diagnosing strengths and weaknesses among co-management units and for exploring 'what if' scenarios.

Empirical Models: : Bayesian networks (BNs)

- Netica software for constructing BNs is user-friendly, inexpensive, and easy to learn. <http://www.norsys.com/>
- Further information about BNs together with detailed guidelines for their construction (with examples) can be found in Halls et al (2002) and Chapter 14 of Hoggarth et al (in press).

Further Reading: Cowell et al (1999).

Web resources:

http://en.wikipedia.org/wiki/Bayes'_theorem

http://en.wikipedia.org/wiki/Bayesian_inference

Population Dynamics Models: ASPD Models

- Age-structured population dynamics (ASPD) models apply growth and mortality rates to individual cohorts (age-groups) recruited to the fishery in order to determine how the overall population number or biomass will respond to age- or size-dependent rates of exploitation or management interventions.
- These types of models are often referred to as **Dynamic Pool Models**.
- Project R5953 modified a basic ASPD to include density-dependent growth, mortality and recruitment to explore the effects of hydrological modification (flood control) and management interventions of floodplain fishery yields. This ***Dynamic Pool Model for Floodplain Fisheries*** is described in detail by (Halls et al 2001).
- A combination of hydrological conditions and age-dependent fishing mortality rates drives changes to numerical and biomass density. These in turn effect rates of recruitment, growth and natural mortality (Figure 3).

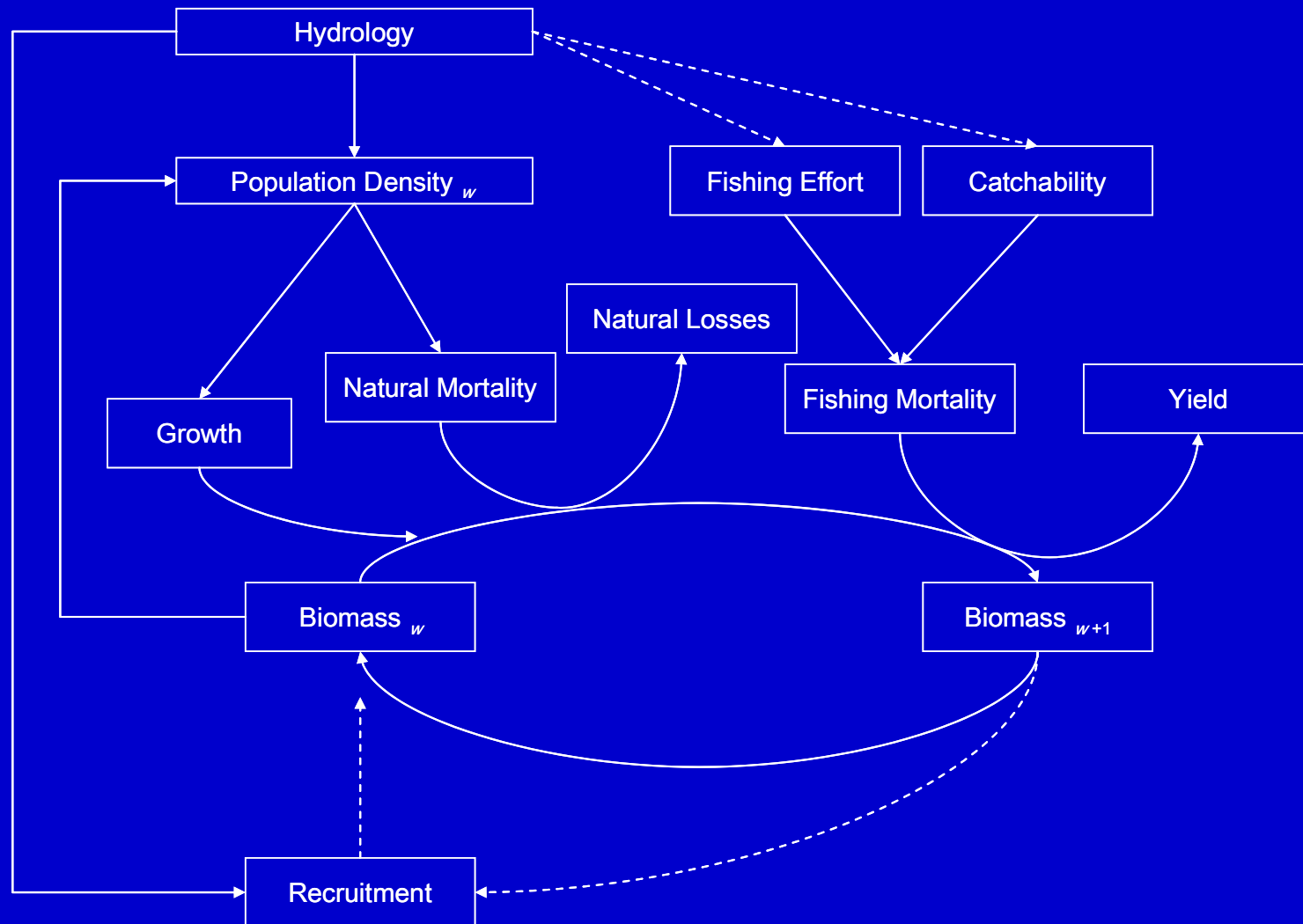


Figure 3 Schematic representation of the population model illustrating the processes by which the biomass in week w becomes the biomass in the following week, $w+1$. The weekly process is repeated for the 52 weeks of the year, after which recruitment, determined by the surviving spawning stock biomass, is added at the end of week 52. Solid lines indicate direct influences or operations and broken lines indirect influences or occasional operations. Source: Halls et al (2001)

Population Dynamics Models: ASPD Models

- The model has been fitted to landings of a small but widely abundant cyprinid, *Puntius sophore* in Northwest Bangladesh (see Halls et al 2001). This species is abundant throughout Bangladesh and southern Asia, and shares similar life history characteristics with *Henicorhynchus* species that dominate catches in the Tonle Sap and Lower Mekong rivers.
- A simple hydrological model was used to generate weekly estimates of flooded area and volume required as an input to the model.
- The model was used to explore the potential effects (benefits) of water level management within a flood control scheme and introducing closed seasons (to reduce overall effort) on fisheries yield.

Population Dynamics Models: ASPD Models

- The results indicated that beyond a flood water height (~ 9m at the study site) fish production is determined mostly by dry season water levels with production increasing almost linearly with increasing mean dry season water levels (Figure 4).
- The model predicted that yield can be improved by **retaining more water during the dry season**.
- Lost yield arising from the reductions in flood season water heights caused by flood control embankments could be compensated by **increasing the dry season water levels** (volumes) on modified floodplains.

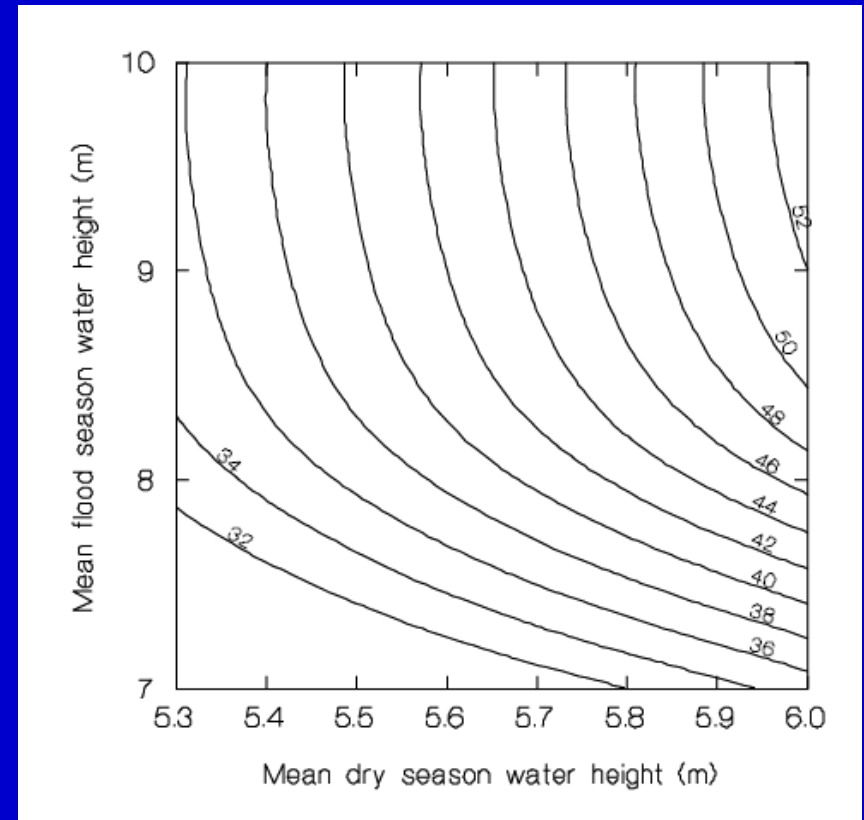


Figure 4. Isopleths of yield $\text{kg ha}^{-1}\text{y}^{-1}$ for *P. sophore* in response to different combinations of dry and flood season water levels. Source: Halls et al (2001).

Population Dynamics Models: ASPD Models

- Closing the fishery during any month of the year was predicted to increase production by at least 30% (fishery was heavily over-exploited).
- Annual production was found to be maximized by removing ~ 85% of the fish biomass during October (and closing the fishery for the remaining 11 months of the year) just prior to the drawdown (ebb flood) when fish have achieved the majority of their year's growth and before losses due to density-dependent mortality become significant. The surviving fraction of the spawning stock maximizes next year's density-dependent recruitment.
- Such a highly seasonal fishery is unlikely to be practicable or equitable given the prevailing access rules, particularly in Bangladesh.
- The greatest gains for the smallest initial sacrifices were predicted to be achieved by closing the fishery during the dry season (January-April) when small catches comprise the few remaining spawning individuals experiencing low rates of growth and natural mortality.
- A closed season toward the end of the dry season could alternatively take the form of dry season reserves (see accompanying presentations on harvest reserves).
- Full details of the model algorithms and results can be found in Halls et al (2001).

Other applications

- The model has also been used to explore how water within flood control schemes (compartments) can best be managed for the benefit of **both agriculture and fisheries** (see Shanker et al 2004; 2005). The results of these investigations have been summarised in the accompanying presentation on **sluice gate management**.
- The model has also been used to examine the effects of **dam releases** of different depth and duration on downstream resident fish populations (see Halls & Welcomme 2004).

BEAM 4 - Bio-Economic Analytical Fisheries Model

- BEAM4 is a multispecies, multigear yield-per-recruit simulation model
- It can be used to assess the potential impacts of different fishery management measures (effort controls, closed seasons, minimum size limits etc) on fishery yields
- Software originally published by FAO as 'BEAM4' (Sparre & Willmann, 1991). Now available as the general analytical YPR model in FiSAT software suite (downloadable from FAO web site)
- Model applied by DFID project R4791 to floodplain river fishery data from Bangladesh, Indonesia and Thailand (see Hoggarth & Kirkwood, 1996)

BEAM 4 - Model inputs

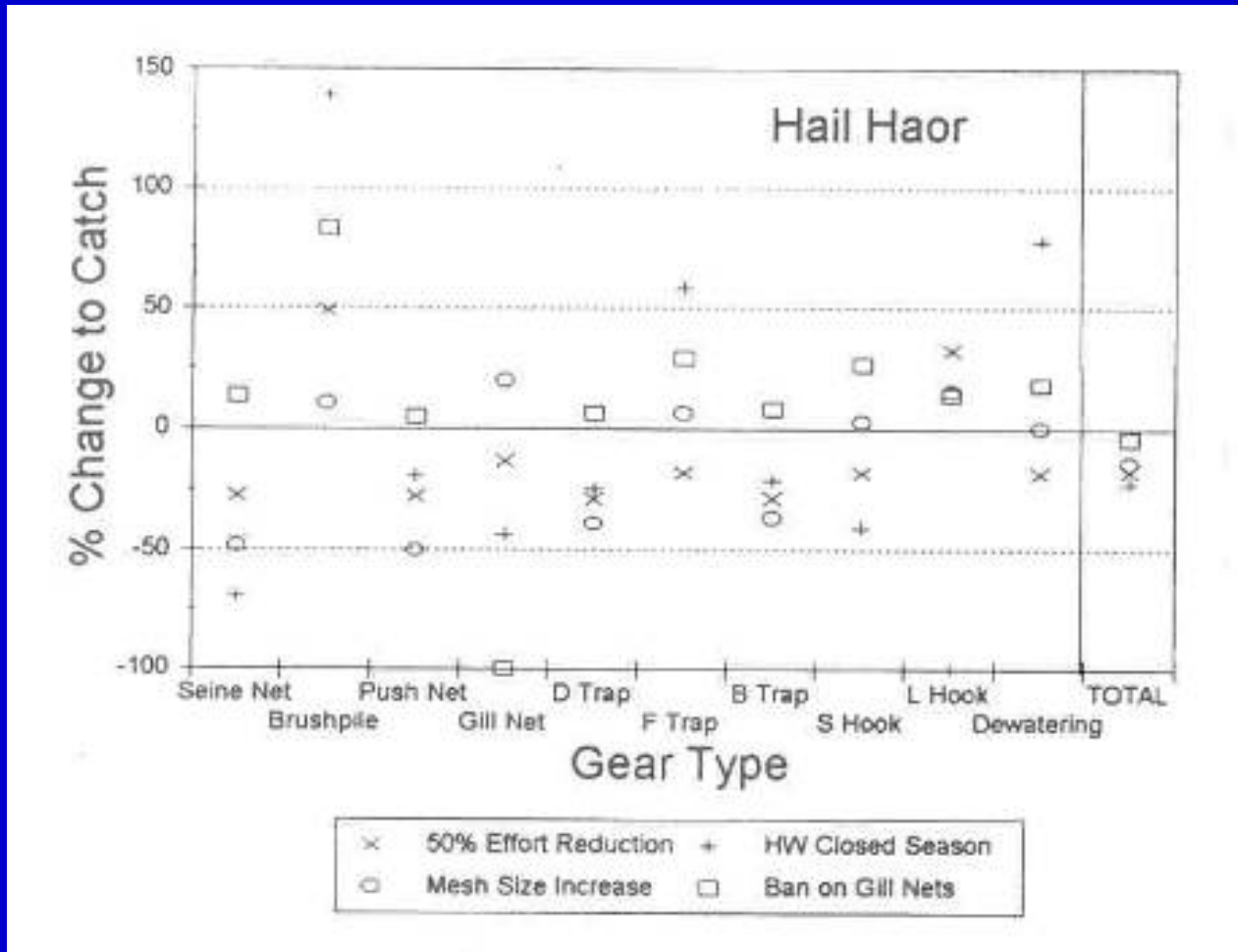
- BEAM 4 has high data requirements, but approximate inputs can be estimated from a short time series sample of length frequency data (or from a sample of aged fish, for species where ageing is possible)
- Data inputs:
 - Biological parameters for each species in the model - growth rates (K , L_{inf} , t_0) and mortality rates (Z and M) - estimated in this analysis from a 9 month time series of length frequency samples (ELEFAN method)
 - Size selectivity of each gear type for each species, determined approximately from the length frequency data
 - Seasonality of each gear (modelled by entering the actual monthly fishing efforts of each gear)
- For the R4791 analysis, the model was fitted for up to five species guilds in each fishery (each country study site) and up to ten fishing gear types

Growth and mortality rates used in R4791 BEAM 4 analysis

Study Sites Fish Species Guilds	Von Bertalanffy Growth Rates		Mortality Rates (yr ⁻¹)	
	K (yr ⁻¹)	L_{inf} (cm)	Natural, M	Fishing, F^1
Bangladesh				
Large Carps	0.3	75	0.6	4.1
Large Predators	0.7	70	0.9	2.1
Medium-sized Blackfish	0.7	30	2.4	2.5
Small Whitefish	0.7	15	3.0	2.4
Small Shrimps	'1.0	'4	'3.0	'1.9
Indonesia				
Floodplain Predators	0.7	65	0.9	2.0
River Predators	0.6	58	0.9	2.0
Medium-sized Blackfish	0.65	28	1.2	2.0
Medium/small whitefish	'0.7	'20	'1.5	'2.0
Large Shrimps	'1.0	'30	'2.0	'2.0
Thailand				
Snakehead Predators	0.5	65	0.9	2.0
Medium-sized Blackfish	0.6	30	1.2	2.0
Medium-sized Whitefish	'0.6	'30	'1.2	'2.0

¹ Maximum fishing mortality rate, for fish at lengths fully selected by all gear types.

Example results from R4791 BEAM4 Analysis



- Figure shows % change to catch for each gear type (listed on x-axis) for four alternative management measures (shown by symbols)
- Note variation in effects of different measures on each gear, but limited overall benefits of any measure, shown as TOTAL, averaged across all gears
- These measures would change the allocation of catch, but not the total

References

- Dooley, J., Jenness, J., Aguilar-Manjarrez, J. & Riva, C. (in press.) African Water Resource Database (AWRD). GIS based tools for aquatic resource management. *CIFA Technical Paper*. No. 33. Rome, FAO, 2005.
http://www.fao.org/fi/eims_search/publications_form.asp?lang=en
- Grainger, R.J.R. & Garcia, S.M. (1996). Chronicles of marine fishery landings (1950-1994): Trend analysis and fisheries potential. *FAO Fisheries Technical Paper*. 359. Rome, FAO. 51pp. http://www.fao.org/fi/eims_search/publications_form.asp?lang=en
- Haddon, M. (2001). Modelling and quantitative methods in fisheries, Chapman Hall, London, 406pp.
- Halls, A.S. & Welcomme, R.L. (2004). Dynamics of river fish populations in response to hydrological conditions: A simulation study. *River Research and Applications*. 20: 985-1000. <http://www3.interscience.wiley.com/cgi-bin/jissue/109857602>
- Halls, A.S., Burn, R.W., & Abeyasekera, S. (2002) Interdisciplinary Multivariate Analysis for Adaptive Co-Management. Final Technical Report to the UK Department for International Development, MRAG Ltd, London, January 2002, 125pp.
<http://p15166578.pureserver.info/fmsp/Home.htm>
- Halls, A.S., Kirkwood, G.P. and Payne, A.I. (2001). A dynamic pool model for floodplain-river fisheries. *Ecohydrology and Hydrobiology*, 1 (3): 323-339.
<http://www.ecohydro.pl/index.php>
- Halls, A.S. 1999. *Spatial models for the evaluation and management of Inland Fisheries*. Final Report prepared for the Food and Agriculture Organisation of the United Nations (FIR 1998 Plansys 232200120).

References

- Hilborn, R. & C.J. Walters (1992). Quantitative Fisheries Stock Assessment. Choice, Dynamics and Uncertainty. London, Chapman Hall.
- Hoggarth, D.D., Abeyasekera, S., Arthur, R., Beddington, J.R., Burn, R.W., Halls, A.S., Kirkwood, G.P., McAllister, M., Medley, P., Mees, C.C., Pilling, G.M., Wakeford, R., and Welcomme, R.L. (in press). Stock Assessment for Fishery Management – A Framework Guide to the use of the FMSP Fish Stock Assessment Tools. *FAO Fisheries Technical Paper* No. XXX. Rome, FAO. 2005. XXX pp.
http://www.fao.org/fi/eims_search/publications_form.asp?lang=en
- McCullagh, P. & Nelder, J.A. (1989). Generalized Linear Models. London, Chapman & Hall.
- MRAG (1993) Synthesis of Simple Predictive Models for Tropical River Fisheries. Report to the Overseas Development Administration. 85 pp.
<http://p15166578.pureserver.info/fmsp/Home.htm>
- MRAG (1994) Synthesis of Simple Predictive Models for Tropical River Fisheries - Supplementary Report. Report to the Overseas Development Administration. 29 pp.
<http://p15166578.pureserver.info/fmsp/Home.htm>
- Shankar, B., Halls, A.S., & Barr, J. (2005). The effects of surface water abstraction for rice irrigation on floodplain fish production in Bangladesh. *Int. J. Water*, Vol. 3, No. 1, 2005.
- Shankar, B., Halls, A.S., & Barr, J. (2004). Rice versus fish revisited: on the integrated management of floodplain resources in Bangladesh. *Natural Resources Forum*, **28**: 91-101. <http://www.blackwell-synergy.com/toc/narf/28/2>

References

- Welcomme, R.L (1985). River Fisheries. FAO Fisheries Technical Paper 262, FAO,Rome. http://www.fao.org/fi/eims_search/publications_form.asp?lang=en
- Welcomme, R.L. (2001) *Inland Fisheries: Ecology and Management*. Fishing News Books, Blackwell Scientific, Oxford, 358pp.
- Zar, J. H. (1984). *Biostatistical Analysis*. New Jersey, Prentice Hall. 718 pp.

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Project details and credits

FMSP Project R5953 – *Fisheries dynamics of modified floodplains in southern Asia*

- Start Date: 03/1994
- End Date: 03/1997
- Project Collaborators:
 - MRAG (Dan Hoggarth, Ashley Halls);
 - CRIFI, Indonesia (Fuad Cholik, Agus Utomo, Ondara);
 - BAU Mymensingh (M.A. Wahab, Kanailal Debnath, Ranjan Kumar Dam)
- Key References: MRAG (1997); Halls et al (1998); Hoggarth et al (1999); Hoggarth et al (1999b).
- Project web page: <http://www.fmosp.org.uk/FTRs/r5953/.htm>

FMSP Project R5030 – *Synthesis of simple predictive models for river fish yields in major tropical rivers*

- Start Date: 04/1993
- End Date: 07/1993
- Project Collaborators:
 - MRAG (Ashley Halls)
 - FAO (Jim Kapetsky)
- Key References: MRAG (1993; 1994); Halls (1999); Hoggarth et al (in press); Dooley et al (in press).
- Project web page: <http://www.fmsp.org.uk/FTRs/r5030/.htm>

FMSP Project R7834 – *Interdisciplinary multivariate analysis for adaptive co-management*

- Start Date: 01/10/2000
- End Date: 31/01/2002
- Collaborators:
 - MRAG (Ashley Halls)
 - Reading University SSC (Bob Burn, Savitri Abeyasekera)
 - WorldFish Centre (Kuperan Viswanathan)
 - IFM (Doug Wilson, Jesper Neilsen).
- Key References: Halls et al (2002).