Aquaculture expansion and environmental considerations

Advancing skills are bringing improved yields for aquaculture, which is playing an increasing role in food production. As yet, laws pertaining to aquaculture are poorly developed or poorly applied: its growing impact on the environment is here discussed.

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AS THE RATE of increase of marine fish harvests has dropped to less than one per cent per year in recent years, aquacultural yields which now account for approximately nine per cent of total fish production are increasing at a rate of more than seven per cent per year. It is not surprising then that many countries are looking to aquaculture to provide the increases needed to supply future demand for fisheries products. In addition, the technology for producing high value species such as shrimp, groupers and sea basses is progressing very rapidly. Entrepreneurs are investing heavily in new production facilities while finance ministers tabulate projected foreign exchange earnings from export of the higher priced products of aquaculture. In Southeast Asia where fish are extremely important in the diet, more than 10 per cent of the total volume and 16 per cent of the value come from farmed fish and shellfish.

Several factors — increasing demand, improving technology and under-utilized resources — lead to the conclusion that rapid expansion of aquacultural activities can be anticipated over the next two or three decades. It can be further anticipated that much of the expansion will be in brackish- or salt-water where competition with other users of resources (land, water) is less than for freshwater culture.

It is important, therefore, to raise the question of the environmental impact of these activities, which often take place in the environmentally important coastal zones or in waters used for many purposes. In addition, many cultured species and their pathogens are being transported indiscriminately to new locations, especially in the tropics where controls are few. There are, however, both negative and positive aspects of aquaculture and both will be addressed in this article. The former should be well understood so that negative impacts can be minimized in the course of development and probable costs and benefits evaluated prior to initiation of aquacultural projects. The latter are discussed here because environmentalists often overlook them.

This discussion is arranged with respect to the several environments where aquaculture is practical, and only the most important effects are addressed.

Coastal marine and brackishwater aquaculture

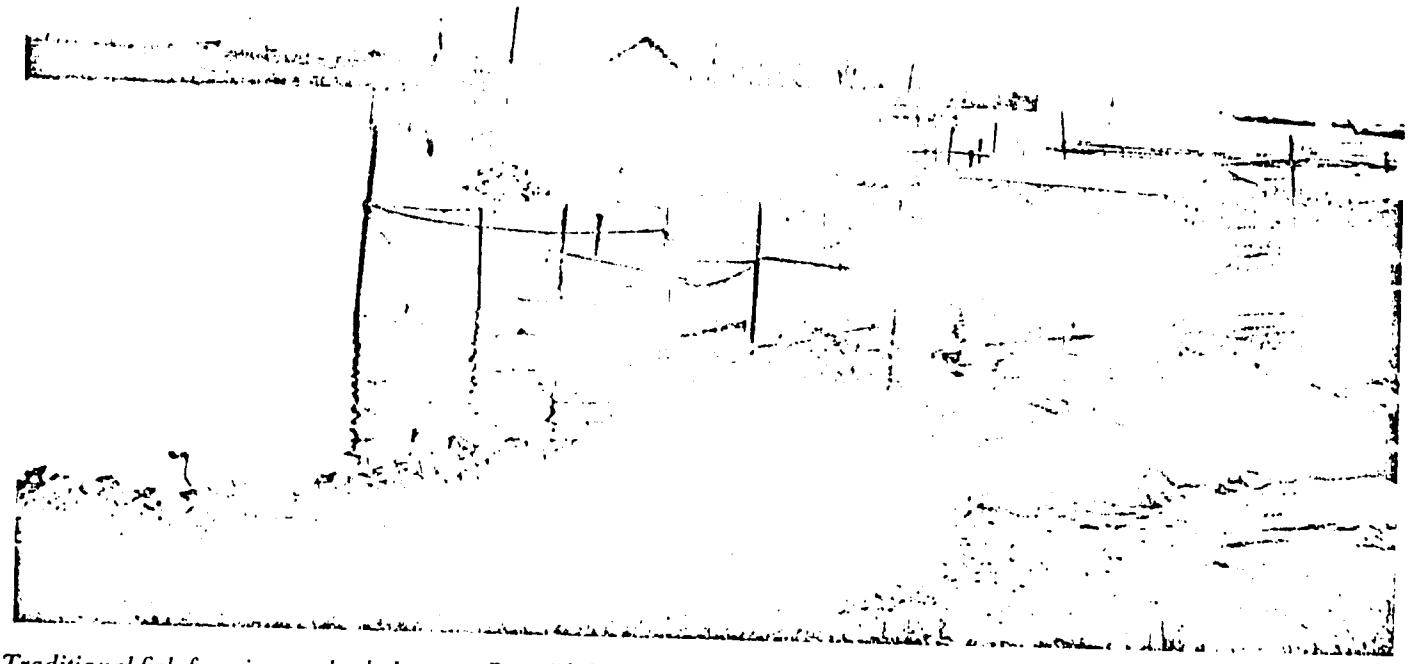
Scope

Traditional extensive culture of milkfish, mullets, bivalve molluscs and shrimp in Asian and Mediterranean countries accounts for conversion of moderately large areas of coastal lowlands into ponds or management of shallow water areas as shellfish farms. For example, coastal areas under extensive pond culture are: Philippines 176,000 ha, Indonesia 192,000 ha, Thailand 25,000 ha and India 12,000 ha. As techniques for rearing marine species (especially shrimp) have improved, some of the traditional ponds have been upgraded for more intensive culture, and large areas of coastal mangroves or marshlands are being converted to ponds (*eg* in Ecuador).

The mangroves and coastal lowlands previously had little direct economic value to owners, or in many cases they were government property, so developers have acquired possession at little or no cost and conversion is usually encouraged by governmental and developmental agencies. The conversion of coastal lowlands to ponds is the aquacultural activity most urgently requiring attention by environmentalists.

Impact

The mangrove swamps are one of the most poorly understood natural environments of economic importance. They are a source of firewood, charcoal, wood chips, forest products, fish and game and have value in stabilising the shoreline.



Traditional fish farming methods Laguna Bay, Philippines. ICLARM.

They are also probably of some direct importance to coastal fisheries as nursery grounds and as sources of nutrients. On this latter point scientists disagree because direct relationships have not been quantified or even clearly demonstrated in most cases. While the debate continues, the mangrove forests are disappearing.

Although we do not know how to evaluate the losses of mangrove swamps to aquaculture, it certainly would be prudent to establish reserves at regular intervals along the coasts where no disruption will be permitted. The ironic fact is that the mangrove zone is usually not the best zone for intensive aquaculture, and trends are definitely toward intensification of shrimp and fish culture.

Only rather extensive culture methods can be used within the tidal zone (the mangrove zone roughly speaking) without adding expensive steps to the farming process. This is because ponds constructed correctly for intensive culture should be placed above the high tide level so they can be drained and dried between crops. For this reason the land with slightly higher elevation than the mangroves (still often with salt-laden soils) is a better choice for aquaculture, providing the option of maintaining a coastal strip of mangroves even where ponds are constructed.

Losses to present and potential users of the mangrove swamps are seldom evaluated even when data on these uses exist. Shrimp farming requires especially large investments in terms of construction, feeds and seed; therefore, powerful business interests are usually supporting shrimp culture development projects. Developing country governments are also supportive because they are interested in encouraging production of this exportable, high value product. The consequence is that little attention is given to environmental effects of these developments.

Essentially all trees, and all wildlife and fish production are destroyed in the process of pond construction, and roads, watercourses and dykes change or restrict natural movement of water.

Few positive environmental effects can be identified for coastal aquaculture. Mosquito production may be reduced in swampy areas converted to ponds because of consumption of larvae by fish or shrimp, and there is likely to be a net flow of nutrients seaward from the developed area which may be beneficial or harmful.

Freshwater ponds

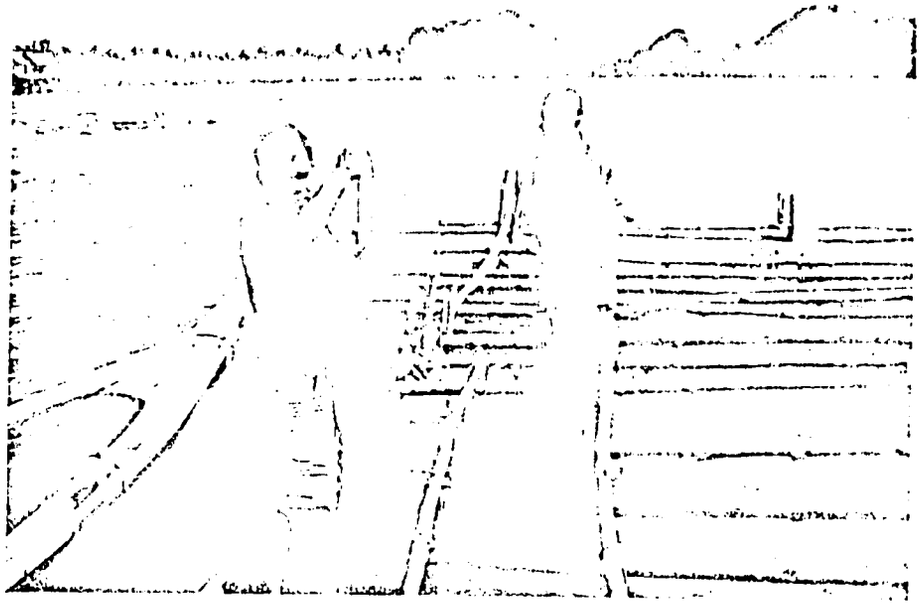
Scope

As freshwater aquaculture has a longer history, for example in China, than marine or brackishwater culture, techniques are better established and more than half the world's production today is from freshwater ponds. In south-east Asia one-fourth of the total production from aquaculture is derived from freshwater ponds. They exist in a variety of environments and climatic conditions, wherever soils are fine enough to hold water and sufficient freshwater is available. In the tropics small-scale freshwater aquaculture is being encouraged widely as a source of supplemental income and food in rural areas remote from the sea.

As agricultural residues and wastes are being used to an increasing extent in aquaculture (recycled in ponds), and as water for irrigation is used increasingly for aquaculture, integrated aquaculture-agriculture is becoming an established part of the agricultural scene.

Impact

Few negative effects of freshwater culture can be identified, in fact it is often encouraged because of the positive effects, many of which are related to multiple uses of the stored



Two village fishermen of the Phang Nga Bay lift a fat 'string' of freshly harvested mussels, a delicacy in Thailand. FAO/Peyton Johnson.

water in poor rural areas. Aquaculturists may choose to dump wastes into natural waters as a means of disposal, especially when very intensive culture is practised and wastes are flushed rather than recycled through natural processes.

The wastes are basically animal faeces, dissolved metabolic wastes and waste feed, and as such can be dealt with as wastes from other animal husbandry. While wastes can be viewed as plant nutrients, their net impact on natural waters is likely to be negative, especially near the outfall, depending upon dilution factors.

Ponds certainly occupy land that could be utilized for other purposes and aquaculture consumes water by way of evaporation and seepage. Aquaculture is therefore a competitor with agriculture for resources including feeds and fertilizers in addition to land and water.

The accumulation of wastes in the pond bottom soils is an addition of organic matter that generally improves the soil for agriculture, should the pond be converted back to agricultural use. In fact aquaculture has been tested as a method of reclaiming desert soils lacking organic matter, but results have not been conclusive.

Use of small dams and ponds high in a watershed for multi-purpose water conservation and fish culture is an approach that has been pioneered by Auburn University in Alabama, USA. When correctly engineered these ponds help maintain local water tables, retard runoff, conserve soils, produce fish and provide supplemental water supplies where needed for livestock and other uses. A more beneficial set of environmental effects can seldom be identified!

Small multi-purpose ponds of this type are used successfully in regions of Panama and Thailand where water is in short supply seasonally. A variation is the common use in the USA of farm ponds to water livestock, rear fish for sport fishing and store water for emergency uses, such as fire fighting or irrigation.

Waste recycling through aquaculture- integrated farming, is a rapid and valuable means for use of wastes, some of which would otherwise be a nuisance. Animal manures have many potential uses, of course, so the most beneficial use economically must be determined in each locality. Other wastes such as rice straw, water hyacinth and food industry residues which have few uses can be composted for use in fertilizing ponds. Such use as opposed to burning or dumping is a positive step.

One category of food processing wastes used to an increasing extent in aquaculture is fish waste including trash fish. Sewage either before or after primary or secondary treatment, and human wastes, have been used as fish pond fertilizers with success under a variety of circumstances and with minimal health risks where fish are cooked. Some aquatic plants, especially water hyacinth, may be grown specifically to remove undesirable nutrients and other chemicals from wastewater.

A related form of recycling, the use of waste heat in aquaculture to increase growth rates and extend growing seasons, has applications, especially in temperate countries, since growth of coldblooded animals is directly related to temperature. To the extent that use of waste heat for aquaculture averts its release into the natural aquatic environment, the environmental effect is positive.

Cages, pens and shellfish

Scope

This unlikely grouping of aquacultural activities is made because there are a number of similarities among these activities when viewed from the environmental standpoint. Commercial culture of fish in cages (floating) and pens (including the entire water column) is relatively new, while culture of bivalve shellfish is very old. They are similar in that both use an apportionment of natural waters for private farming operations and therefore environmental impacts on common property resources are direct and immediate. In fact both depend upon the common property resources adjacent to their property for the successful production, *eg* to maintain flow of clean, aerated water with natural food organisms and to carry off waste products.

Recent development of simple but effective technologies for construction of pens and cages, for cleaning nets and for anchoring cages, and the availability of synthetic netting materials have made cage and pen culture economically feasible and in many situations quite profitable. Species reared range from plankton feeders (milkfish and tilapia) to carnivores (groupers and sea basses) with a range of others fed pelletized feeds.

In some developed countries environmental regulations have prevented most development; trout, salmon, yellowtail and tuna are

exceptions. In developing countries, on the other hand, where food needs outweigh environmental concerns, both marine and freshwater cage and pen culture are increasing very rapidly in public waters.

Shellfish culture (oysters, mussels, clams) has long been a standard mode of food production but wide use of new, more intensive techniques for raft, pole and hanging culture has introduced new environmental problems.

Impact

The most obvious negative impact of cages and pens and structures for mollusc culture is that they are an impediment to navigation and fishing. They physically occupy space previously utilized by fishermen in many cases, so directly limit fishing. They are often placed in shallow, near-shore waters where fishing is best and where aesthetics is a factor. Placement of cages in deeper waters offers several advantages related to water quality and could help avoid the negative impacts mentioned here.

A most serious negative impact of cages, pens and suspended shellfish culture is the pollution of surrounding waters and the bottom with wastes. The wastes are the normal metabolic wastes of animals, faeces, pseudofaeces of shellfish, and waste feed. The waste dilution problem is aggravated by the restriction of circulation, normally resulting from water currents, caused by the presence of numerous cages, large pens or concentrations of poles or hanging cultures of shellfish.

Simply enclosing large areas with nets can significantly reduce circulation, as the Japanese have learned with their yellowtail culture. Rapid accumulation of fish wastes, sediment, and feed wastes has occurred in enclosed bays used for yellowtail culture. The accumulation of 'mats' of wastes beneath salmon cages has been observed, and large accumulations of faeces and pseudofaeces of shellfish commonly occur in intensive cultures.

For marine and brackishwater cage and pen culture most fry and fingerlings used are harvested from natural waters and therefore raise an additional issue of competition with capture fishermen, some of whom harvest adults of the same species.

In developing countries where cage and pen cultures have developed most rapidly the greatest problems have revolved around conflicts with fishermen and legal issues of ownership and control. The common property nature of lakes, coastal marine waters and rivers used for these aquaculture activities may result in undersirable competition among aquaculturists, as well as between fishermen and aquaculturists, and use rights more often are determined by possession or tradition than by legal procedures.

Intensive aquaculture in natural waters depends upon exchanges with surrounding waters to maintain sufficient levels of oxygen, to produce plankton for food and to dilute dissolved waste products resulting from the activity. As the wastes are essentially nutrients directly or indirectly useful to plants this 'pollution" may be beneficial in some instances.

Introduction of nutrients in either marine or freshwater environments may have overall beneficial effects. An interesting application with possible beneficial effects would be the use of lakes adversely affected by acid rain for cage culture on a controlled basis. The wastes from the aquaculture would contribute nutrients and minerals (especially calcium) to these acid lakes, encouraging phytoplankton production and increases in pH. A controlled eutrophication of small lakes could be a beneficial side effect of cage culture.

Ocean ranching and stocking of natural waters

Scope

The rearing and release of young fish for growth at sea or in other natural waters and subsequent recapture is termed 'ocean ranching'. Whether or not it is aquaculture might be debated; however, it is a fisheries activity with potential environmental impact. Most attention has been given to salmon in this regard but many valuable anadromous or catadromous fish also have potential for ranching.

Of potential importance are sturgeon, sea bream and striped bass while fish such as mullets, shads and several others have potential for ranching, especially in the tropics. Japanese, Russian, Canadian and US stocking of salmon in the north Pacific is the best known and most successful example of ocean ranching.

Impact

While few effects on the physical environment can be envisioned from ranching, possible impacts on the fauna are more likely. Expansion of the range, *eg* of Pacific salmon into Chile, may affect competing or prey species or may result in the introduction of new diseases.

Stocking of depleted species to re-establish populations in areas where natural populations have been decimated can have positive effects on the fauna. Examples are the restocking of south Pacific reefs with giant clams, some salmon and sturgeon stocking, stocking of shellfish following mortalities, and considerable stocking of sport fishes. The risk of introducing new diseases in this process is high, especially with shelifish.

Species introductions

Scope

The introduction of exotic species deserves special consideration because it is now relatively easy with jet travel and because it is widespread. Many of the species are introduced for aquaculture although similar transplantations are also carried out for purposes of biological control, especially of mosquitoes, water weeds and snails.

Impact

Aquaculture is often supported by governmental groups or by influential businessmen or industrial groups that have little difficulty in moving species around the globe. Examples

of negative impacts are common. An American crayfish introduced to Europe carried a fungal disease that destroyed a European species over much of its native range. The Java tilapia was widely introduced as a desirable culture species and has become established throughout the tropics as a pest species, in some cases out-competing native species and perhaps replacing some.

Catastrophic shellfish mortalities in Europe and North American have been associated with introductions of new species or stocks. Shrimp culturists are beginning to suspect that some species carry viral diseases to which the carrier species have become accustomed but which are pathogenic to other species. Numerous other examples exist.

The most common problems are naturalization of the introduced species, undesirable competition with endemic species and the transfer of new diseases to the endemic species. The International Council for the Exploration of the Sea has a Working Group on Introduction of Non-Indigenous Marine Organisms which has prepared a Code of Practice for introductions.

The advantages of introductions, as with other animal husbandry, are potential improvement of stocks, or identification of more desirable culture species for a given set of environmental conditions. Species such as rainbow trout, several tilapias, sea basses and oysters have been transplanted with very desirable effects.

Policies and precautions

Aquaculture is certainly here to stay and can be expected to become an increasingly important form of animal husbandry. In most countries laws pertaining to aquaculture are either poorly developed or poorly enforced. It is important for the environmentalist to consider policies and precautions that can be recommended to reduce negative impacts without seriously increasing costs or reducing the effectiveness of the production of fish and shellfish. Several examples of such steps are listed below:

1 Natural mangrove reserves should be maintained at regular intervals along the coast. Until we understand the value and ecological relationships of mangroves better it is desirable to keep reserves too large rather than too small.

2 Construction for coastal aquaculture should be above the mangrove zone, on barren salt flats when possible, and a coastal strip of mangroves or coastal marshland should be maintained wherever possible.

3 Legal clarification of the ownership of coastal lands in developing countries should be encouraged.

4 Economic and socio-economic analyses of the alternative uses of resources required for freshwater aquaculture (land, water, labour, fertilisers, feeds and crop residues and manures) should be emphasized.

5 Conflicts between fishermen and other 'common property' users of natural waters and the private aquaculturists should be addressed directly with due consideration given to aquaculture as a legitimate use of these waters.

6 Considerable attention should be given to species introductions and transfers to formulate enforceable legislation that allows transfers but limits the risks of such transfers by:

a encouraging transfers of eggs rather than juveniles or adults to limit risks of spreading diseases,

b standardizing treatments for common disease organisms for eggs or animals being shipped,

c enforcing culture procedures which limit risks for escape and establishment of introduced species,

d use of quarantine procedures for species with potential pathogens,

e use of 'disease free' certification programmes,

f experimentation to evaluate impacts of competition with or predation on endemic species.

7 Strengthening of enforcement of existing regulations, especially in developing countries.

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Enumerators and questionnaires

The use of enumerators necessarily introduces biases in the data collected. While it is impossible to eliminate the 'enumerator effect', steps should be taken to minimize it through the proper selection, training and supervision of enumerators as well as attention to details of questionnaire design.

In addition to their suitability to conduct interviews, the enumerators selected should, to the extent possible, have the same ethnic background and if possible be known to the target population. This facilitates their acceptance by the latter and enhances their ability to explain the questions in terms and concepts the respondents understand. The latter is very important for standardisation, and will be improved upon even more if the questionnaire format is translated into the local language.

Great attention should be paid to developing the questionnaire, to be sure it taps the precise information required, to phrase it so that it enhances the recall of the respondent, and to standardise it to lessen "enumerator effects". Evidence suggests that the more precise the questions, the more likely the respondent is to recall and relate the answer. On the whole this is more tedious for both the enumerator and respondent, but if fatique can be avoided, it is far superior in the accuracy of the data produced.

The accuracy of enumerators is enhanced by training them so that their understanding of the terms used in the questionnaires and the procedures for administering them is standardised. In training enumerators, the ILCA Kenya team asked them as a group to translate the proposed questionnaires into the Maa language. Considerable debates followed which were instructive to both the enumerators and the researchers. Once the questionnaires were standardised and pretested, role playing was used for further training, with the researchers trying to approximate all conceivable problems. Lastly enumerators were observed while they administered the questionnaires to non-sample households. If at all possible, one should start training more than the required number of enumerators so that at the end of training one will have a better selection on the basis of their observed performance.

If a questionnaire is at all complicated, the enumerators will still be learning in the initial phases of administration. Close supervision will be required in checking the responses so that errors (either in format design or administration) can be corrected before they are made repeatedly. The first set of data collected by the enumerators should be analysed as quickly as possible to assess its quality.

One cannot over-emphasise the high degree of vigilance required to ensure good quality data in survey work. (For a detailed discussion of quality control and correction of enumerator bias using analysis of variance, see Zarkovich, 1966).

Data type

Not all events are equally well remembered. In terms of probability of good recall, events can be scaled along two dimensions: frequency and regularity. Events which are regular are less likely to be remembered individually, but producer estimates of their occurrence are likely to be adequate. Irregular events which occur rarely (such as livestock transactions) are likely to be remembered individually, but frequently occurring irregular events will pose great difficulty in recall and will necessitate high frequencies of questioning. Labour inputs and expenditures fall in the latter category.

Although this section concentrates on recall, it must be noted that information on certain types of events (e.g. treatment of animals) might best be gathered by actual observation rather than questioning. However, for most data, observation is far more time consuming and consequently far more expensive than recall.

Frequency of visits and end effects

The frequency of visits needed depends to a large extent on the type of event to be recalled (or observed). The frequency will also depend upon the depth of data desired on the event in question. For example, if detailed questioning about decision-making is desired, greater frequency would be helpful.

All surveys based on recall suffer from "end effect", i.e. the difficulty of specifying the limits of the period for which

information is requested and the tendency of respondents to include events from outside this reference period. In multiple-visit surveys, the frequency of the visits will normally define the reference period, which is normally the time lapsed since the last visit of the enumerator. End effect problems occur with the first interview as the end point of the period of reference is often unclear. It is strongly recommended that the data from the first interview be excluded from analysis as it is invariably over-reported. Single-visit surveys suffer particularly from end affect problems unless the period can be clearly specified. Collinson (1972) advocates limited visits for certain data collection and stresses the need to use time frames that fit a local natural or cultural cycle.

Single-visit formal surveys. Single-visit formal surveys form an integral part of FSR methods as currently advocated by CIMMYT (Byerlee et al, 1980). Their primary role is to quantify and verify the hunches which have emerged from the initial informal survey. Single-visit surveys are most appropriate for collecting information on variables (such as herd structure) for which a single objective measurement will suffice. They may also be used to collect general data on a relatively small number of variables particularly when the essential parameters of the production system are already well understood. For well remembered and registered events (e.g. livestock transactions) single-visit surveys may be able to elicit time-depth data on actual events. For non-registered events, single-visit surveys rely more on the producer's ability to estimate, based on general experience, rather than recall actual events; as such, they produce averages rather than indicate variability, and are inadequate when time series data are required.

Multiple-visit formal surveys. Multiple-visit formal surveys have several advantages over single-visit surveys. They provide time series data, are more likely to reflect actual events rather than estimations, benefit from learning on the part of both the enumerator and respondent. However, as the number of visits is increased, given the same amount of resources, the number of households must be de-

creased. Again, careful attention must be paid to the nature of the data required in order to decide between measurement and sampling biases.

In literate societies, it is possible for respondents to keep written records of the variables under study. This is almost impossible in pastoral systems research. However, Swift (1981) believes it may be possible to find, hire, and train local residents to collect time series data, with a minimum input from senior researchers.

When time series data are desired, decisions must be made as to whether the recording will be continuous or non-continuous. For example, rather than recording continuous expenditures, it might be possible with care to subsample within the important seasons.

Respondent cooperation and bias

Whatever the information collected, it is necessary to distinguish between the respondent's ability and his willingness to respond. The producer's ability to respond to the questionnaire is largely a function of survey design: whether the questions are well phrased and solicit information which it is possible for him to remember. Multi-visit surveys appear to have a learning component, so that some improvement in recall occurs, provided that it is not offset by respondent fatigue.

A respondent's willingness to respond, however, is a function of his general level of cooperation as well as the sensitivity of the data solicited. FSR researchers frequently note value of early interventions in increasing the general level of cooperation. Nevertheless, there are still likely to be social/psychological factors which encourage inaccurate, and especially selective, reporting. These may be due to a desire for greater prestige, fear of shame, or a cultural taboo on certain topics. Case studies and participant observation are particularly useful to evaluate and adjust for such reporting biases.

Having briefly reviewed types of data collection methods for household level research, this session now turns to specific

topics and methods. We will discuss, in turn, livestock transactions, household budget, and labour studies.

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