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A Methodology for Visual Estimation of Abundance Applied to Flyingfish Stocks

PIERRE FREON
Pole Caraibe
Orstom BP 81
97256 Fort de France, Martinique

ABSTRACT

A method for estimating flyingfish abundance is proposed. It is based on counting fishes, when forced into flight by a research vessel following predetermined transects, regrouped on regular distance units. In this way, the method is related to acoustic survey methodology.

Different variables (biological, physical and environmental), that may directly or indirectly influence the abundance estimation or the stock distribution, have to be collected during the survey. The method of observation (direct or using a camera) and of data processing is described, as well as the equipment required to store most of the data directly in a computer unit.

INTRODUCTION

Flyingfish are a major source of protein, employment and revenue throughout the eastern Caribbean, often ranking first or second in importance by weight of all species landed in most countries of the area. Approximately 4,000 metric tons per year are landed in the different islands. The need for fisheries management and thus for stock assessment is evident for this species (Mahon *et al.*, 1986).

The lack of reliable fishing effort and age structure data and the heterogeneous nature of the fishery prevent the use of conventional methods of population dynamics. Flyingfish are a wide-ranging pelagic species, thus their spatial distribution and stock composition are poorly known. A broad research survey is necessary now in order to obtain these and the other basic population data. Since fishing alone does not provide the most accurate biomass estimates for pelagic species, the use of hydroacoustic methods for biomass estimation is being tested in Martinique.

An echo-survey trial using a downward-facing, fixed transducer on a laterally-towed body was made (Gerlotto and Oxenford, pers. com.) in order to determine whether flyingfish remain deep enough below the surface to be detected. Results show that because these fish swim very close to the surface, this method was not appropriate. Additional echo-survey investigations should be made with a deep laterally-towed body, similar to those used for pelagic fish (Diner and Masse, 1987), but looking upwards. However, even when not disturbed, the flyingfish remain so close to the surface that they will be indistinguishable from the surface echo except under ideal weather conditions rarely observed offshore. Thus a visual survey method is proposed here that is very similar to the echo-survey approach but avoids this acoustical problem.

Flyingfish are observed to jump out of the water when a (research) vessel approaches and we can therefore take advantage of this behavior to observe the fish directly rather than using sophisticated devices (sonar, underwater camera, etc.) which rarely enable counting and species identification. Former researchers have made use of this behavior as it can be seen in the bibliography compiled by Fabres (1986) (Breder, 1929; Hubbs, 1933, 1937). More recently, some quantitative estimations have been done onboard Soviet ships during long trips across the oceans, but little is known about the methodology used (Shuntov, 1973; Zuyev and Nikol'skiy, 1980; Nesterov and Grudtsev, 1981).

The following paper describes the variables which should be collected in a visual survey and details the proposed methodology, equipment required and data processing. In the final section, further methodological requirements are considered.

VARIABLES OBTAINABLE DURING A VISUAL SURVEY

Biological variables

Fish density (expressed in number of fish) can be reasonably estimated assuming that the proportion of fish forced into flight by the boat is either constant or bears a known relationship to density, and on the water surface area involved in this fright behavior. A relative index of density can at least be estimated using the same methodology from one survey to the next. Then the biomass (or at least an index of abundance) can be calculated from the fish density.

Species composition is generally easy to obtain from a trained observer who is able to identify the different species according to their pectoral fin (wing) color, type of flight and maximum size (Oxenford, pers. com.).

Size structure can be roughly obtained by direct observation or by video playback and picture calibration when only three or four age/size groups allow an adequate description of the population demographic structure. The fast growth of these species and their short longevity (Mahon *et al.*, 1986) probably allow the use of structural models with such rough data.

Physical and chemical variables

The following variables may be important for understanding flyingfish distribution or the flying behavior and therefore may be relevant for the calibration of the method. It is difficult at this stage of our knowledge to classify these variables in order of priority. Nevertheless, the variables which are felt to be less important than the others are presented in brackets.

Position of the boat geographically must be recorded periodically during the survey in order to allow mapping of the resource.

Boat speed is also needed as it probably influences the distance of takeoff of the flyingfish and the proportion of fish school flying. Also, influencing the estimation of density from counts per time interval., *i.e.*, counts must be corrected for speed.

Engine revolutions per minute should be recorded since the noise (frequency and intensity) may be an important source of stress. This variable is closely related to the previous one if the same boat is used for each survey.

Boat course during each transect can be useful to compare with the sun position in order to test any behavioral change according to the light direction could also affect ability to accurately observe.

(Boat drift) can provide information on the current strength and direction when the wind does not strongly influence the boat drift.

Wind velocity and direction could influence the direction of the fish flights and their range (Breder, 1929; Hubbs, 1937).

Swell direction may have a similar effect.

Swell height may also influence the flight range and the conditions of observation.

(General meteorological data) such as the air temperature, humidity, atmospheric pressure, etc. are unlikely to be determinant variables in a tropical area since, for example, air temperature is fairly constant and correlated with water temperature. However, these variables are easily available from the usual meteorological station on board and may be of some value.

Water color could be an important variable affecting flyingfish distribution and abundance. At least three major types of water can be classified by quality, namely: oligotrophic blue water offshore, richer green water with phytoplankton, and turbid brown water.

Water transparency can also provide an index of water quality associated with the color. It may also influence the distance at which fish see the boat, if vision is at all important.

Water temperature, even if relatively stable in the tropical area, may provide an interesting description of the water mass, especially in upwelling areas.

Water salinity is probably not a determinant variable in itself (except for the low values observed in the coastal area), but is often a good indicator of the water-mass.

Hour of observation is probably an important parameter because it may influence the fish behavior and the quality of the visual observations according to boat course, as mentioned previously.

Weather type may also change the fish behavior and the quality of the observations (rain, dust, clouds, etc.).

Moon phase and position must be recorded if the survey is also done during the night (see later). It may also affect fish behavior during the day.

Presence of floating debris or FADs must also be recorded because they can aggregate the fish, especially during the spawning season.

SURVEY METHODOLOGY

Survey design

The survey design will depend mainly on three factors: the stock characteristics (such as density, distribution, migration, etc.), the objective of the survey, and the means available (for example, time, boat(s), crew, equipment, etc.).

A minimum knowledge of the stock's population distribution is required before designing the survey. If such information is not at hand pilot surveys covering an extensive area during different seasons would be necessary.

Different objectives may be assigned to a survey, but the more common are the following:

1. To assess the spatial distribution of the stock at any one moment (instantaneous picture),
2. To study the fish migrations by repeating the previous survey in different seasons,
3. To estimate the total biomass of the stock,
4. To study the relative biomass from one survey to the next,
5. To estimate the biomass of one component of the stock *e.g.*, the spawning stock or the recruitment (ϕ-group age class).

As is the case for acoustic survey design, the area to be visually surveyed must be covered by preestablished transects. Special attention must be given to the distance between transects, their position and their orientation with respect to the randomization requirement. Of equal importance is the sequence length of cumulative observations, also named elementary sampling distance unit (ESDU), expressed in distance or in time. These factors may seriously limit the final biomass estimation if they are not properly established (Johannesson and Mitson, 1983; Jolly and Hampton, 1987).

In the case of flyingfish, the position of the transects with respect to the depth is probably not important around the Caribbean islands (for the insular shelf edge may be different). More attention should be paid to the hydrological structure (upwellings, currents, frontal structures). Our knowledge of the Caribbean hydrology and of the flyingfish preferendum may not be good enough at the moment to give any reliable suggestions for special survey designs, although the ideas presented by Mahon (1986) considerably advanced the subject. As for any large pelagic stock distributed in open water, random sampling, proportional allocation or any *a priori* stratification of sampling effort seem unrealistic.

The choice between parallel and oblique (zig-zag) transects has been widely discussed for acoustical survey (Johannesson and Mitson, 1983; Laloe, 1985; Jolly and Hampton, 1987) with reference to factors such as: boat time, boat speed, area covered and transect spacing. Formulae proposed by these authors for estimation of the total length of the survey according to these factors can be used to compare the two patterns of survey. This choice does not seem fundamental here because the survey must cover a very large area in two dimensions (at least for the initial pilot surveys) and because there is no indication of the existence of any geographic gradient in the biomass distribution. Therefore the transects must be very long, and parallel transects will not need significantly more time than zigzag transects but will give a more homogeneous sampling of the area. The usual systematic survey grid pattern with a non-randomly selected starting point would be a valid approach because the mobility of the fish would take care of the randomization requirement of the transect position, (Johannesson and Mitsdon, 1983).

The essential question is the distance between transects. The choice must be made according to the type of distribution of the fish (Fiedler, 1978; Barbieri Bellolio, 1981). Since the fish are non-randomly distributed and probably have two levels of aggregation (concentration and "schools") the problem is not easy to solve. The better approach is probably to start with a relatively short distance between transects in a limited area and to make statistical simulations from these first results (Gerlotto and Stequert, 1983). If the boat time is limited, these authors recommended starting with a wide equidistant intertransect spacing during the first part of the survey, and then returning to the richest areas for more dense sampling. The consequences of this approach for data processing will be seen later.

In tropical areas the useful daytime period of visual observation is relatively short (around 10 hours) and constant. As surveys are time consuming it is useful to extend the daily period of observation into the night using artificial lights (or highly sensitive equipment, but this latter solution is very expensive and inconvenient). Of course the results would not be directly comparable to those obtained during the daytime, as for acoustic surveys, because the fish behavior would be different. Nevertheless, the two kinds of observations could probably be intercalibrated more easily than in the case of an acoustic survey. If not, this would mean that they give very different and probably complementary results, and in such a case, the survey design could be established for covering each transect by day and by night.

Each ESDU should cover around 2 nautical miles owing to the large distribution of the stock. It must be remembered that the statistical efficiency of the ESDU is also closely related to the temporal and spatial characteristics of the stock distribution. Its length must be short enough for studying the type of distribution of the resource, but long enough to limit the autocorrelation in the ESDU series (Gerlotto and Stequert, 1983). Moreover, when using short sequences the proportion of sequences without fish detections will increase, and therefore, the video recording can be played back faster if those null sequences are registered during the survey.

It is generally easier to use a time unit for resetting the abundance measurement instead of a distance unit during the survey, considering that the boat speed is relatively constant. According to the boat speed, the length of the sequence should be between 5 and 10 minutes.

If possible the surveys should be done at the same speed. The optimal speed must be determined, but it can be assumed that high speeds allow a good stimulus for flying without disturbing the recording. The main factors for optimizing the speed are probably the daily costs of the boat (type of boat and fuel consumption) compared to the daily costs of the crew (scientists and sailors). Trials using chartered sport-fishing boats could be made to determine optimal speed for causing flight response.

The fishing operation

Biological samples may be desired for validating the species identification and calibrating the size estimation, or for biological studies. In such a case, as for acoustic surveys, one must choose between the ideal solution of using two different boats for the survey and for the sampling, and the cheapest solution of using a single boat. In the case of flyingfish this question is of primary importance because fishing operations using first attraction methods and then passive or active gears generally take longer than the trawling operations used for other species. The problem can be partially overcome if the survey is made only during the day and night is spent fishing in the area of concentration observed during the day. This solution is not optimal, however, because it may be difficult to relocate the concentration, and because one is never sure of catching the same fish observed several hours before. If only one boat is available, a good solution is to limit the fishing station to the place where the fish identification is doubtful (several species and size for example). As the transects are generally long, in most of the cases the time spent between an observation of fish concentration and the next passage of the boat near this point on the following transect will be long enough (Fig. 1). This allows the set of a gill-net that could be recovered a few hours later with a minimum waste of time.

Visual sampling at sea

The principle of the method is known (Breder, 1929): the average fish density along the transect must be estimated for each visual sequence, and then the biomass of the area surveyed can be obtained by multiplying the fish densities by the corresponding surfaces along the transect in order to cover the whole area. The allocation of surface for each sequence can be done using different graphical methods described below.

Both direct visual observation by an observer placed on the roof of the boat and recording observations using a video-camera and a video-tape recorder allowing playback in the laboratory should be used.

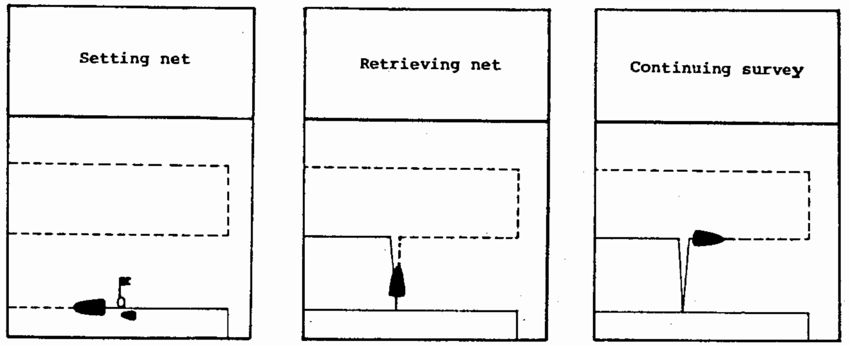


Figure 1. Example of a survey track design to minimize boat time when lengthy fishing operations are being conducted.

Two different levels of knowledge of the abundance may be required by the survey, according to the objective(s), either:

1. estimation of a relative index of abundance, or
2. estimation of the absolute biomass

The methodology will be different according to the requirement of the survey. If only a relative index of abundance is needed, it will be important to conduct each survey under the same conditions, with the same equipment and, as far as possible, with the same observers, and to assume that there will be no predominant influence by uncontrollable external factors from one survey to the next. In the case of absolute biomass estimation, additional conditions are required in order to estimate the real density and then to extrapolate to the whole population. In each case, two approaches can be used:

1. A total count of the number of fish flying when the boat is passing would be sufficient to determine relative indices of abundance, assuming one can find a practical method for counting. To obtain an estimate of actual

abundance, two further criteria would have to be met:

a. The "flying area" relative to the area of the school (or concentration) would need to be determined. This is not easy to determine using only the observed distance of flight from the boat, because the fish may swim a long distance below the surface before flying, as suggested by Breder (1929);

b. The proportion of fish school which flies in this area will have to be determined. From surface observations, Zuyev and Nikol 'skiy (1980) estimated the vertical distribution of flyingfish (mainly *Exocoetus volitans* in the eastern tropical Atlantic) and their avoidance behavior when a boat is passing. These authors estimated that an average of 40% of the fish emerge from the whole depth occupied by the flyingfish (0 to 5 metres) with a higher probability of emergence of the fish located in the upper zone:

2. The "flying area" should be subsampled in order to reduce the errors or bias due to the physical limitations of the eye when counting at sea or on a video screen. The optimal size of the subsample and where on the boat to sample from (laterally or over the bow) would have to be determined.

The optimal sample area may be very small in the case of high abundance (schools) without significant loses in the precision of the estimates. However, in the case of low abundance (scattered fish), a small sample area may lead to poor precision. In order to overcome this problem, when reading video recordings made with a wide angle lens, a temporal or spatial subsample can be imposed systematically or randomly on the screen (see last section). A better solution would be to use two cameras with two different focal lengths: the largest would be used for subsampling the other, with the advantage of allowing easier fish tracking. However the problem of the position of this subsample must be solved.

As the distribution of fish takeoffs and flights is not random around the boat but is at least dependent on the wind direction (Breder, 1929) and on the distance from the boat (Zuyev and Nikol 'skiy, 1980), the position of the sample (or of the subsample) is important. Breder (1929) observed that flyingfish along the south-east coast of the U.S. flew into the wind in the ratio of 1 to 3. This author sampled alternatively to starboard and to port during periods of one-half hour. This methodology can be applied to shorter periods as the 5 to 10 mn ESDU previously defined. If the main objective is to obtain a relative abundance index, the assumption that the gradient of the number of fish flying along one side of the boat is independent of external factors that cannot be held constant during the survey (such as swell, wind, light intensity and direction) must be verified before choosing the sample area. The influence of these factors on the flight distribution must be studied carefully, especially if the sampled area covers less than half of the potential "flying area." If the influence of those uncontrollable external factors is large, then the sampling approach would be unsuitable before quantifying these effects. This may require years of research.

If an estimate of actual abundance is required, the ratio of fish flying to those remaining below the surface must be statistically estimated under different conditions (controlled and uncontrolled) in order to make a proper statistical inference to the total "flying area" and to the whole area under survey.

In any case of sampling, the observations and the views recorded must be obtained from the same place and must cover the same area on the sea surface with reference to the boat. The observer could use a solid frame made with four boards as a viewfinder, previously adjusted to give the same field of view as the camera. The main difficulty would be to stabilize the camera movements, especially on a small boat and under bad weather conditions. Operating the camera manually for long time periods would be difficult and may introduce an overestimation of the biomass because of the natural tendency to orient the camera towards the higher fish density.

Data recording

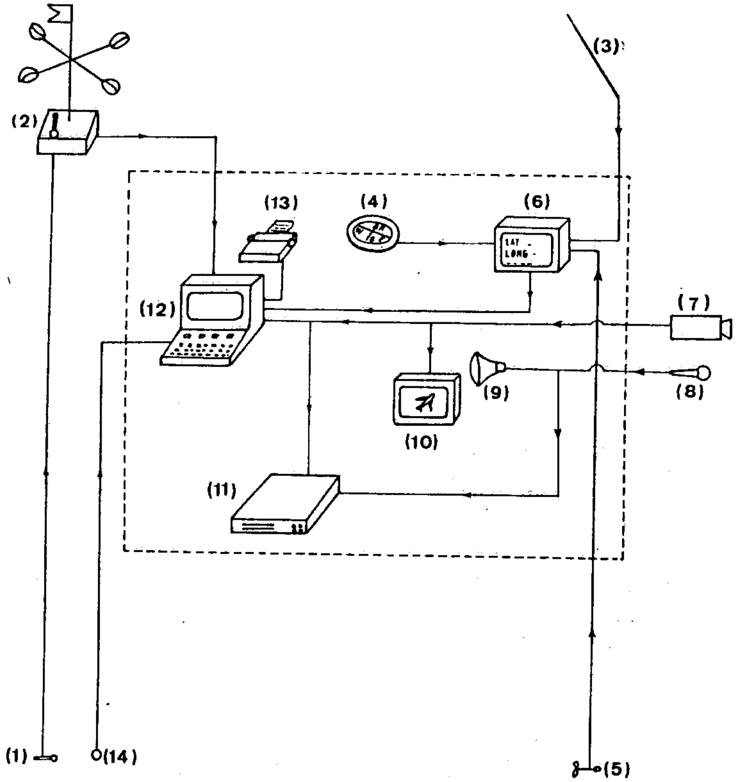
The observer should use a microphone connected to both a video recorder and a loudspeaker through an amplifier in order to communicate with a second scientist inside the boat (Fig. 2). The second person would record on a log-sheet for each time interval the cumulative observations and the main physical data (Fig. 3). A second log-sheet must be used by the crew for the other variables. Even if all the biological and physical data are automatically recorded by the video recorder and by a computer, this manual recording is a useful precaution in case of technical problems. Moreover such manual recording at sea save time later in the laboratory, as previously mentioned.

The information given by the observer must be encoded, brief and clear. The conventionally used species name must be short. The number of size categories must not exceed four in order to avoid subjective interpretation. The abundance should be classified in three categories:

- individual fish,
- scattered fish (or schools)
- schools.

For individual fish, the "lab-scientist" can record all the observations during a sequence. Scattered fish or school characterized by the cumulated time of appearance using a chronometer, if an additional scientist was available on board. If not, the abundance estimation would be done at the marine station, using the video recording.

All the other variables mentioned above can be obtained and recorded automatically, without stopping the boat, using modern recording instruments



(1) seawater temperature sensor
(2) meteorological station
(3) satellite antenna
(4) compass
(5) log (video camera
(8) microphone
(9) loudspeaker
(10) video screen
(11) video tape recorder
(12) desktop computer
(13) printer
(14) salinometer
- - -Limits of the Laboratory

Figure 2. Electronic equipment setup for visual survey of flyingfish schools.

ESDU #	Time	Transect #	Speed	Comptuter record #	Video tape counter #	Species and length group (Small :S; Medium :M ; Large : L)														
						H.a.			H.s.			H.r.			H. spp.			Un Know			Other		
						Ind	Dis	Sch	Ins	Dsp	Sch	Ind	Dis	Sch	Ind	Dis	Sch	Ind	Dis	Sch	Ind	Dis.	Sch
1	8:05	1	7	1	110	Ms																	
2	8:10	1	7	2	162								S1										
3	8:15	1	7.5	3	215							no fish											
4	8:20	1	7.5	4	259																Dolphin	L3	

Figure 3. Example of the main log sheet for a visual survey. Ind = individual fish, Disp = dispersed fish, Sch = schooling fish.

interfaced with a desktop computer (see below). The only measurements difficult to handle without stopping the boat are the color of the sea and the water transparency. As high precision is not needed for these two variables, a simple color chart could be used for the first one, with around 8 colors (2 blue, 1 green-blue, 2 green, 1 green-brown, and 2 brown for example). A rough index of water transparency could be obtained by using a meter long white vertical tube fixed to the boat, and/or a white towed body behind the boat and controlled with a measuring pulley and a winch. Both devices must be installed near the stern in the fish flight.

If night surveys are conducted, powerful floodlights would have to be installed at the bow. Around dawn and dusk it will probably be impossible to make good observations, not only because of poor visibility but also because fish behavior is probably changing and unstable at this time. These periods could be used for fishing.

EQUIPMENT

Boat

The boat should be large enough to allow long trips far offshore, a total crew of around 12 people for working by rotations over 24 hours, and a small laboratory. In order to obtain comparable results between surveys, it is essential to use the same boat because the flying behavior probably differs from one boat to the other, according to undetermined parameters (*e.g.* size of the boat, color, noise frequency and intensity). The hull of the boat must be cleaned before the survey because different degrees of fouling may change the boat noise and therefore modify the fright signal intensity. Under ideal conditions, a recording of the boat noise spectra should be conducted (Bercy, 1984).

Video Camera

A high resolution video camera is desirable. It is easier, for technical reasons, to find such equipment in black and white. Some preliminary trials should be done to determine whether or not lack of color is compensated for by an increase in the resolution. These trials should be done with different species and for different sea colors. The angle of the objective is also very important and must be chosen according to the camera resolution and the sampling methodology (total surface, sample, and eventually subsample).

If possible, the camera should have an internal clock which displays the time and the date on the screen and records this information on the video tape. An alternative solution is to get this information directly from the tape. This feature makes the videocassette identification and sequence finding safer and easier. A connected keyboard for printing titles is another useful feature (but less essential).

A polarizing filter would be useful in limiting the disturbance from sun light reflected on the sea surface.

The camera stabilization system must be studied in detail not only to provide a stable view, but also to provide a constant location of the view with respect to the boat. A gimble system with an heavy weight may give satisfactory results.

Viewfinder

The viewfinder should give the same field of view as the camera lens. In a small boat with sharp rocking motion, it may be very uncomfortable for the observer to use the viewfinder for a long watch. In such a case, large lateral boards may be used instead of a viewfinder, for limiting the field of view to a predetermined angle. Such boards must also be used during the initial methodological surveys with two observers surveying each side of the boat (Fig. 4).

TV monitor

An ordinary TV set can be used on the boat. A large screen with high definition is recommended for fish counting, back at the laboratory.

Video recorder

An ordinary video tape recorder can be used. It must have a precise revolution counter with digital display allowing frame by frame playback must be possible.

The recent development of videodisks and compact disks or optical disks using a laser may allow more convenient storage with a large capacity and a fast random access.

Microphone

The microphone must be directional and protected against wind disturbances. An intercom system could replace the simple system presented in Figure 1 and would have the advantage of allowing communication from the laboratory to the observer.

Computer and peripheral devices

An ordinary desktop computer can be used with a small printer for editing the recorded parameters during each ESDU (useful for control and as a backup). An internal clock would be useful if the time trigger does not come from the camera or from the video recorder. If a small boat is used for the survey, taking a hard-disk on board is not recommended, unless portable equipment is available. A floppy-disk reader using a 3.5 inch diskettes is satisfactory at sea. The most important criterion for choosing the computer is the ability to interface it with the electronic equipment used for measuring the environmental

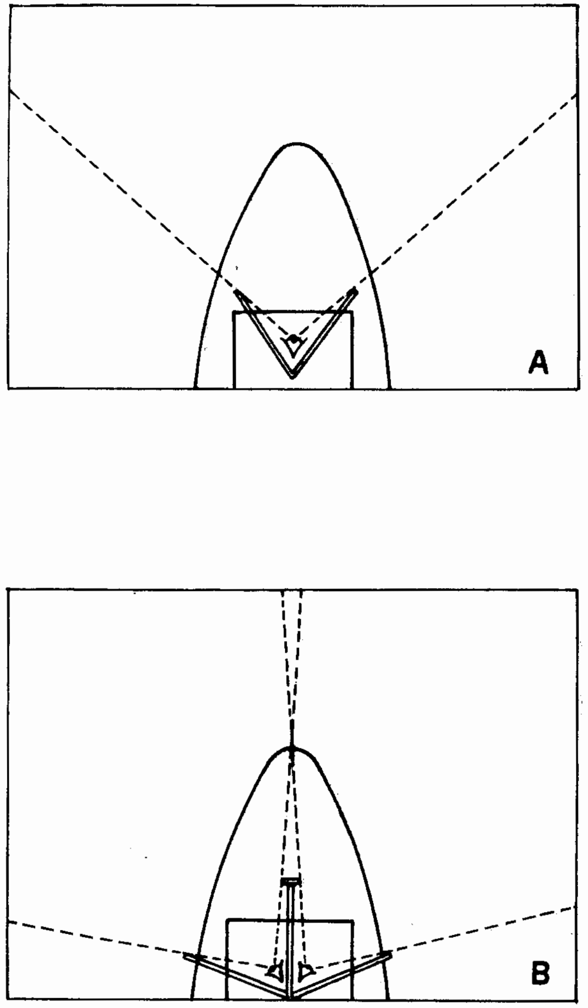


Figure 4. Limitation of the field of view by boards for one (A) or two (B) observers placed on the cabin roof of the boat.

parameters. The number of slots for parallel and/or series interfaces must be large enough, and the acquisition speed (number of bauds per second) must be consistent with those of the electronic equipment. A multi-task computer would allow data input from the keyboard (such as swell direction, color of the sea) during the automatic acquisition of other parameters.

A plotter would be very useful for mapping results after the survey.

Navigational aids

A satellite navigator is strongly recommended because it allows quick and efficient navigation with the actual position of the boat immediately available and automatically recordable on the computer. In addition it can provide useful information such as the time, date, boat speed and drift.

Meteorological station

The automatic meteorological stations provide air temperature (dry and wet), subsurface water temperature, wind direction and speed. The last two parameters may or may not be corrected according to the boat course and speed. If not, this can be done later with the computer.

Fishing gear

The normal fishing gear used by local fishermen can be used. Nevertheless, for a survey the criteria for gear selection are different from those of a commercial fishery. The catching efficiency of the gear is not as important as its low selectivity and its handling speed when a second fishing boat is not used during the survey. The monofilament gill-net is one of the most often employed gear types (Harding, 1986) despite its selectivity. Hanging such a net above the water along the side of the boat by using two lateral masts, could be tried in order to see if it is possible to sample without stopping the boat.

It is recommended that special attention is paid to statistical data on the landing of commercial fishing boats during the survey period, with detailed information on the species, fish length, and location of the catches.

Floodlights

Powerful halogen floodlights are recommended. They will allow measurement of water transparency with a vertical tube, foil, or the Secchi disk, even though this measure will have to be intercalibrated with daytime measurements.

DATA PROCESSING AND ANALYSES

Four main steps must be carried out at the marine laboratory after the survey: data interpretation and storage (especially for the density estimation), abundance mapping, abundance estimation and fish length estimation.

Data interpretation and storage

After the survey, it will not be necessary to playback the whole video tape at the marine laboratory. Two situations require only the visual data given by the observer during a particular ESDU:

1. The sequences without fish detection at all (probably more than half of the ESDU).
2. The sequences with nothing other than individual flight detections spaced far enough apart to allow reliable counting and a good communication between the observer and the "lab scientist" at sea.

For the other ESDU the playback of the videotape must be used if more than a rough mapping of the resource is needed.

Two approaches can be used for estimating the density, namely:

1. The static approach using some sampled individual frames.
2. The dynamic approach using the total recording for tracking the fish movements.

The static approach would consist of randomly sampling some frames on a time basis, and then counting the number of fish on the screen. It should be indicated whether the take-off starting point and direction are randomly distributed around the boat. At sea, I usually observe a density gradient of the takeoff distribution around the boat, and a strong polarization of the flight direction related to the avoidance behavior of the fish and to the wind direction. These phenomena limit the use of the static approach but some methodological studies may help to correct the subsequent bias. Using a frontal view, the major bias would be an overestimation of the density when the fishes are "pushed" by the boat and go along with it for some distance, remaining in the picture longer than in the theoretical case of a random distribution of the flights. If the flight distribution is symmetrical with respect to the longitudinal boat axis, a lateral view could reduce this bias.

Another disadvantage of the static approach is the poor quality of the frames provided by stopping the videotape reading. Sophisticated equipment enables both video recording and photographs to be taken with the same lens, but the cost of printed photographs would be too high for a reasonable sampling density. A 16 mm camera used for sampling at a low rate (one view per 30 seconds, for example) would be a less expensive solution. The use of current video technology for pictures that give a high resolution at a reasonable cost should be investigated.

The dynamic approach is in fact the one used by the observer counting the number of fish appearances at the sea surface. The main inconvenience of this method is the difficulty of counting when the density is high and when the boat is moving under bad weather conditions, especially if a long focal length lens is used. Two techniques of counting the number of fish can be used:

1. Counting only the number of fish takeoffs at the moment they jump out of the water.
2. Counting the total number of fish on the screen, both crossing the sea surface when taking-off or entering the screen from one side when the take-off occurred off the screen.

The first technique seems the more appropriate one if absolute density estimation is required. Indeed, it overcomes the bias introduced by the movement of the fish relative to the boat. The two main inconveniences of this technique are that it reduces the number of fish counted and it is difficult to apply because the instant of takeoff is not easy to capture on film. The fish is hard to detect before the pectoral fins are extended, because of the low contrast between the color of its back and the color of the sea. Repeated playbacks will be necessary to separate the true takeoffs on the screen from the ordinary flights crossing the screen.

The second technique of total counting is much easier to use. The main disadvantage is making a reliable inference to the real fish density. For a survey aimed at providing a relative biomass, this technique seems suitable. If an absolute biomass is needed, then further methodological studies must be carried out in order to provide the conversion factor to estimate the fish density from the total flight count, as intended by Zuyev and Nikol 'skiy (1980).

The density ρ may be estimated by $\rho = CM$, where C designates any conversion factors corresponding to any approach or counting technique allowing the real density to be calculated from the counting, and M indicates the number of fish counted during an ESDU within a certain field of view.

Abundance mapping

A typical chart showing an actual survey design together with the plotted M values is presented in Figure 5 from Gerlotto (pers. com.). From this map subsequent analysis proceeds along two lines, one aimed at data presentation, the other at deriving absolute estimates. Other presentations of the distribution results, such as geographic maps, bar graphs or three dimensional representations, are reviewed by Johannesson and Mitson (1983).

Abundance estimation

The equation for flyingfish abundance N_B within the area A of the survey, can be written in a simple form when considering only one species:

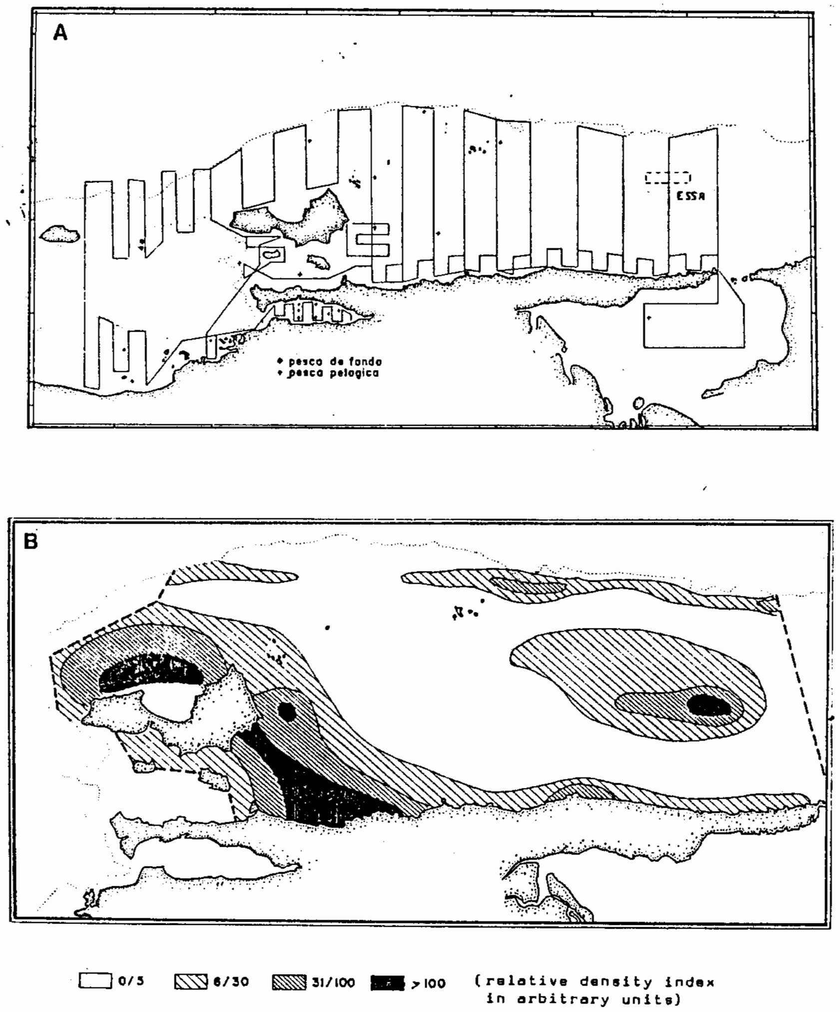


Figure 5. Example of acoustic survey mapping (from Gerlotto pers. com.) (A) survey design, (B) density mapping

$$N_B = \rho_A \cdot \int A\,dA$$

where ρ_A is the mean value of fish density observed per EDSU within the area A and expressed in numbers of fish.

The equation for fish biomass W_B can be written as:

$$W_B = \sum W \rho_A \int A\,dA$$

where W is the mean weight of the length group of the given species, estimated from the length-weight relationship.

Several methods are commonly used on acoustic surveys to apply the previous formulae to a real case. The two traditional methods: algebraic and geometric are based on the assignation of each sample observation o_1 to a corresponding rectangular area called an "elementary statistical sampling rectangle" (ESSR). For a parallel survey pattern with equidistant inter-transect spacing, all the ESSRs have the same area size and are crossed in the center by the transect (Fig 5). The calculation of the mean of all the ρ_1 observations is given by:

$$\rho = \frac{1}{n} \sum_{i=1}^{n} \rho_1$$

and the total biomass:

$$W_B = \rho\, n\, A = \rho\, n\, \mathrm{ESSR}$$

The only difference between the two methods is the use of the null ρ_1 values. More detail on these two methods and on the post-sampling stratification technique are given by Johannesson and Mitson (1983). This last technique is useful when the fish distribution is heterogeneous in terms of mean density and variance, which is generally the case for pelagic fish.

More recently other survey designs have been proposed with new and different data processing techniques allowing a more flexible design and a greater precision in the biomass estimate and in the confidence intervals, as earlier mentioned. Instead of using ESSRs with two dimensions equal to the ESDU and to the inter-transect distance, the dimension and the position of the ESSR's are fixed independently, in order to obtain a relative independence between the density of each ESSR. MacLennan and MacKenzie (1985) use, for instance, 20 mile-square ESSRs. In this case any ESDU falling inside a particular ESSR will be used for the calculation of the mean density.

As the usual assumption of normal distribution of the O_1 values is generally not true, different techniques of variable transformations are used for acoustic surveys. The observed distributions generally present a positive skewness. They can be expressed by several mathematical models such as: the negative binomial, Polya-Aeppli, Neyman and Poisson distribution, listed in order of decreasing positive skewness (Elliott, 1971; Barbieri-Bellolio, 1981). The negative binomial distribution is probably the most suitable model for flyingfish stocks.

Several workers have shown that the assumption of independence between successive observations of acoustic density is not valid. Bazigos (1976) showed that the auto-correlation of the series has an inflationary effect upon the variance. Nickerson and Dowd (1977) proposed to use a model given by Hogg and Craig (1968) to correct such a bias, while Shotton and Dowd (1975) suggested the use of the cluster sampling estimate of Hansen *et al.* (1953). This last technique has been used from a simulated study by Williamson (1982). Johannesson and Mitson (1983) apply this approach to a real data set. The use of spatial analysis techniques, also called geostatistical approtion, allowing a better variance estimation when the fish are strongly aggregated (Gohin, 1985).

Age size group determination

In addition to the rough estimate made by the observer at sea, a more precise estimation of the fish length can be done at the marine laboratory using the video recording. It is easy to calculate the fish length using trigonometric properties from the following data (camera focal length, camera azimuth, camera height above the sea, fish height above the sea, fish tilt angle, position of the fish in the field of view).

Another approach is to calibrate the camera directly at sea for a fixed position and to use simply a scaling factor. In the case of *Hirundichthys affinis* with allometric growth, this feature can be used for a direct estimation of the size group.

In both cases the final length estimation can be obtained quickly using view processing software and a mouse or a light pencil on the computer.

DISCUSSION

Many uncertainties still remain when considering the feasibility of using visual observations for assessing flyingfish stock abundance. Except for just roughly mapping the resource, the other objectives need a good estimate of the C conversion factors for each species. Experiments using divers, underwater cameras and perhaps echosounders to assess school size and position must be undertaken. These experiments should consider the results of behavior experiments conducted by acoustic survey on a school when the boat passes close to it (Olsen, 1979, 1987; Diner, 1987; Godo and Ona, 1987; Misund, 1987). The usual difficulty with such experiments is to ensure that the observing devices (*e.g.* camera, diver or sonar) do not interfere with the fish behavior.

In order to avoid the presence of two sources of disturbance during the

methodological experiments, the underwater observations may be done from the survey boat using a camera fixed under the bow which can record the fish behavior before takeoff. However, underwater cameras provide a short range of observation with generally poor definition. A bow observation chamber, like the one installed in the "Charles H. Gilbert" research vessel, would be more appropriate but more difficult to get. A literature review of the results obtained with the above vessel, and other methods may give some useful information concerning flyingfish behavior (Breder, 1929; Edgerton and Breder, 1941; Akana *et al.*, 1960; Strasburg and Yuen, 1960; Mann, 1961; Yuen, 1961; Zuyev and Nikolskiy, 1980). However, except for evidence of wind influence, the role played by other physical parameters is unclear and the main factor responsible for the fish reaction (*e.g.* vessel noise, sight of the boat or lateral bow wave disturbance) is unknown.

In order to determine if the engine noise is predominant in determining the fish behavior compared with other sources of stress, an experiment using a sail boat and a motor boat at the same time could be done.

Some experiments or bibliographic studies on human vision must be carried out to establish the optimum field of view allowing reliable observation and counting of dispersed fishes. Obviously the aerial angle must not exceed 50°.

The new techniques of image processing using powerful desktop computers may lead to substantial improvement of the methodology. The view stabilization may be solved by this way. Less obvious is the possibility of directly estimating the fish density by integrating optical changes.

In summary, the most important questions to answer before carrying out a large survey for biomass estimation are:

1. Which kind of boat should be used (size, facilities, etc.)?
2. What is the optimal field of view for the observer and for the camera(s)?
3. What is the optimal location of this field of view (lateral, frontal, distance from the boat)?
4. How to delimit and stabilize this field of view?
5. What is the optimal boat speed?
6. What equipment specifications are required (*e.g.* focal length of the camera lens, interface characteristics for the computer peripherical s, color charts, etc.)
7. What is the variability of the flight behaviour and which parameters control this variability? Special attention must be paid to:
   a. the proportion of fish taking-off
   b. the distribution of the flights with respect to the boat course (symmetrical or asymmetrical) and with respect to the distance from the boat
   c. the variation in flight length

d. the number of flights per fish (statistical description of flight repetitions)

8. How wide is the field of influence of the boat in terms of stimulating a fright reaction?
9. From the above answers and according to the survey objective, which methodology must be used to estimate the fish density or an index of density?

The conversion factor C may eventually be described by:

$$C = f(W, \Theta_1 , H, \Theta_2 ,\Theta_3 , A, V, S, T, N)$$

where W is the wind speed, Θ_1 the angle between the boat course and the wind direction, H the swell height, Θ_2 the angle between the boat course and the swell direction, Θ_3 the angle between the boat course and the sun light, A the sun azimuth, V the boat speed, S the surface (or the volume) of the boat under the water, T the water turbidity, and N the index of the boat noise integrating the frequencies and the noise intensity. This list of parameters is preliminary. It may be incomplete and/or some parameters mentioned may not have a significant effect.

CONCLUSION

This attempt to describe a methodological approach for a flyingfish abundance survey shows that many questions remain unanswered. Although much can be learned from previous acoustic surveys (Venema, 1982) to save time and avoid some mistakes, it is obvious that large surveys cannot be successfully achieved without some preliminary experiments. If these are not done, a loss of time and money will probably result from the first surveys. The method for obtaining relative abundance indices may be available after a few months of experiments, but for absolute biomass estimation many years of research would probably be necessary to reach a satisfactory method giving reliable confidence limits. After 20 years of multi-disciplinary international research, the acoustic method is just reaching this point.

However, if the variability of the flying behavior of flyingfish resulting from the vessel stress is not too high, it may be possible to ask sportboats (motorboats or sailboats) or commercial vessels to carry out some observations of abundance and report them periodically. Such cooperation between oceanographers and commercial vessels has been successfully achieved for many years for recording temperature (subsurface and XBT) and meterorological data. A physical oceanographic data base is now available, covering all the commercial ship routes around the world. Although such information would be subjective for flyingfish, it could be useful for a general mapping of the resource, especially outside the visual fishing grounds.

Visual methods of estimation, commonly used up to the end of the last century, have since been abandoned because they are generally less objective than techniques using modern equipment developed at the beginning of the 20th century. However, the new technology of recent years (video, computer) may result in a comeback of these methods but with a quantitative approach. Such an analysis explains the recent success of remote sensing techniques.

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