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Efficiency of Bottom Sampling Trawls in Deriving Survey Abundance Indices

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Introduction

Annual bottom trawl surveys are commonly used to measure temporal variation in stock size, mortality and recruitment, along with other biological characteristics, of various groundfish stocks under management regulation. In the NAFO area, annual groundfish surveys generally employ a stratified-random design to estimate population abundance indices which are often expressed as mean numbers (or biomass) per standard tow distance or area swept. These survey indices are also used in calibrating fishery dependent models (Sequential Population Analysis) to increase the precision of these abundance estimates. Survey indices are more advantageous because of the rigorous standardization of protocols used to collect data and with the use of small mesh trawls are better for estimating the strength of recruiting year-classes. In the current assessment of many NAFO groundfish stocks, trawl surveys provide the only source of stock size estimates available to fishery managers. Consequently, errors and unexplained variability in survey indices of population size and age composition would seriously impact management decisions.

Generally, researchers have directed their efforts towards increasing precision and accuracy of survey estimates by improving survey designs and analyses to deal with the spatial variability of the target species. Changes in sampling trawl geometry and performance can affect the catching efficiency and also contribute to the bias and sampling variance associated with these survey estimates. The intent of this paper is to examine the role and validity of various assumptions made about the sampling tools used to derive survey estimates. Data on Atlantic cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*) and yellowtail flounder, (*Pleuronectes ferruginea*) will be used to illustrate various concepts[1].

Methods

Sampling trawls

The choice of a bottom trawl for sampling has a significant influence on size composition, species selection and subsequent estimates of abundance and recruitment. For example, in the Canadian surveys of the Grand Bank, the estimates of stock size and age composition of yellowtail flounder derived from small and large mesh survey trawls often differ by an order of magnitude even though the timing of the surveys are one month apart. The ideal sampling gear would catch, with equal efficiency, all demersal life stages of many target species. However, bottom trawls are flexible structures and do not catch all fish in the area sampled during a fishing tow because of changes in bottom trawl geometry, performance and fish behaviour. Thus all sampling trawls are size and species selective to varying degrees. In many countries, it is common to choose a common commercial trawl used in the local fishery as the standard survey trawl and modify it by inserting a small mesh liner into the codend to reduce mesh selection.

Fish capture process

Much of our knowledge about how a trawl catches fish comes from daylight studies of round fish, in particular cod, haddock (*Melanogrammus aeglefinus*), mackerel (*Scomber scombrus*), and herring (*Clupea harengus*). The vessel, trawl doors, sweeplines (here defined as bridles plus ground warps), sand clouds, footgear and net panels present a combination of visual and auditory stimuli to herd the fish into the trawl path and into the net (Fig. 1). A combination of the right attack angle by the sweeplines and towing speed must be sufficient to exhaust the fish. As the fish get closer to the trawl mouth they swim orientated in the direction of the tow (an optomotor response) and when exhausted either turn to swim into the net or over or under the trawl. Swimming speed and endurance of the target species plays a key role in herding and

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[1] The reader is directed to major reviews by Gunderson (1993), Engås (1994), Godø (1994) and Walsh (MS 1996) which I have relied upon as sources of information for this synthesis.

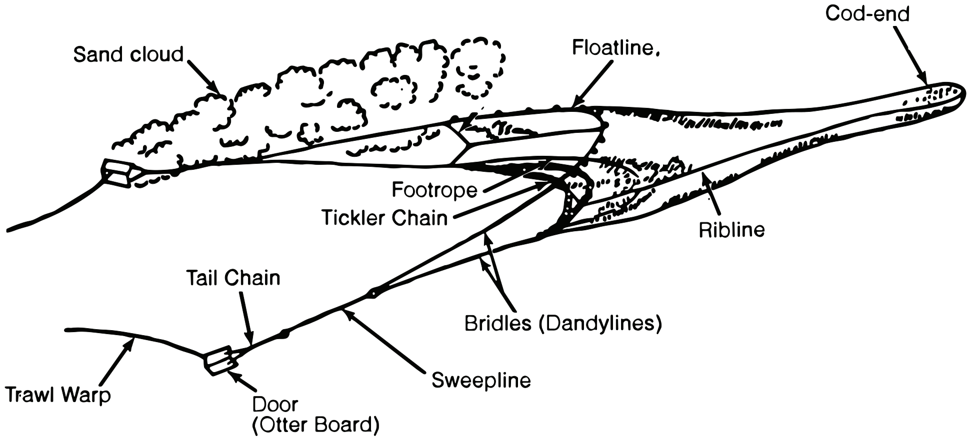

Fig. 1. Drawing of a bottom trawl in action, showing the herding effect of the sand (or mud) cloud generated by the trawl doors (Adopted from Gunderson 1993).

capture success. At night, the visual herding response is reduced and the orientation of roundfish to the tow direction is generally more random. Generally, gear avoidance during the day time is high and at night it is reduced.

In contrast to roundfish, most flatfishes such as American plaice and yellowtail flounder, are non-schooling, bottom dwelling fish and do not react to doors, sweeplines, footgear until these components are very close (0.5 to 1 metre) or collide with them. Flatfishes generally do not show orientation and movement along the direction of the tow and there is very little difference in day and night behaviours. Although flatfishes can avoid capture by escaping underneath the trawl they are never seen to rise upward to escape over the headline nor are they affected by the noise of the survey vessel.

Fishing

The process of catching fish in bottom trawls is a complex interaction between fish and the trawl in three zones and is illustrated in Fig. 2. It begins ahead of the trawl doors (*zone 1*) where selection can be influenced by ship/trawl avoidance reactions with fish moving from the pelagic zone, in response to the vessel noise, into the bottom zone. A proportion of the fish in front of the trawl doors will enter the trawl path between the doors (*zone 2*) and of these fish a proportion will be herded by the sweeplines and the sand clouds created by the trawl doors towards the net (*zone 3*). Since escapement or gear avoidance can occur in any of the three zones, then catchability is affected by size selection, horizontal and vertical spatial distribution of fish in the trawling area and the behaviour interactions of the fish with various physical components of the trawl. Mesh selection (*zone 3*) in survey trawls is often assumed to be negligible, however, in large mesh sampling trawls mesh selection can occur ahead of the small mesh codend liner. For the rest of the text we will be concerned mainly with *zone 2*, the area from the trawl doors to the mouth of the net.

Underlying Mathematics

The main objective of a bottom trawl survey is to derive an index of abundance which is proportional to the true abundance and tracks the relative changes in the population through time. In order to achieve this objective trawl surveys require: 1) complete coverage of the distribution of target species, and 2) a measure of the catchability or fishing power of the sampling gear. In stratified-random surveys average catch-per-tow is extrapolated to the total survey area and it is assumed that catch (C) and absolute abundance (N) are related. In fishery dependent models this relationship is defined by the following familiar catch equation:

$$C = qfN$$

where q is the catchability coefficient and f some measure of fishing effort. Catchability is defined here as the proportion of the stock caught by a defined unit of effort. Although q and f are difficult to precisely estimate in fishery dependent models, in survey trawl data f is standardized by using the same tow duration.

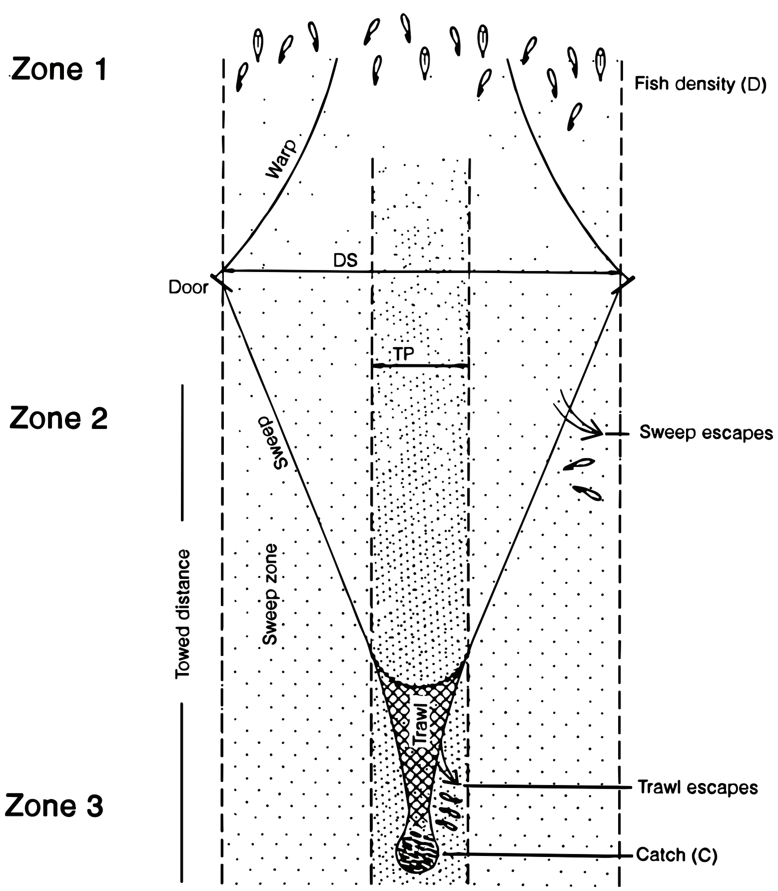

Fig. 2. The three catching zones of influence in the fish capture process. (Adapted from Godø 1994).

The technological changes associated with changing catchability in commercial catch per unit effort (CPUE) data are reduced in scientific surveys by the process of standardization of vessel, fishing gear and survey timing.

In scientific surveys,

$$\mathrm{CPUE} = q_s D$$

Here survey catchability q_s is the proportionality constant between C or CPUE and the true abundance (or biomass) (D). CPUE generally represents catch (numbers or weight) per standard tow length or per unit area. In the NAFO area, the primary sampling unit is the area swept by the trawl (AS) and is generally estimated by the product of the tow distance (t) and wing spread (WS). The true estimate of swept area is probably best represented by trawl door spread (DS), instead of wing spread (see Fig. 2) and will be discussed later.

Catchability q_s of the survey trawl can be further decomposed into availability (q_a) and trawl or catching efficiency (q_e) as seen in Fig. 3 and Fig. 4. The above equation is re-written as:

$$D = \mathrm{CPUE} / (q_a * q_e)$$

Here trawl efficiency, q_e, is the proportion of fish in the trawl path retained by the net.

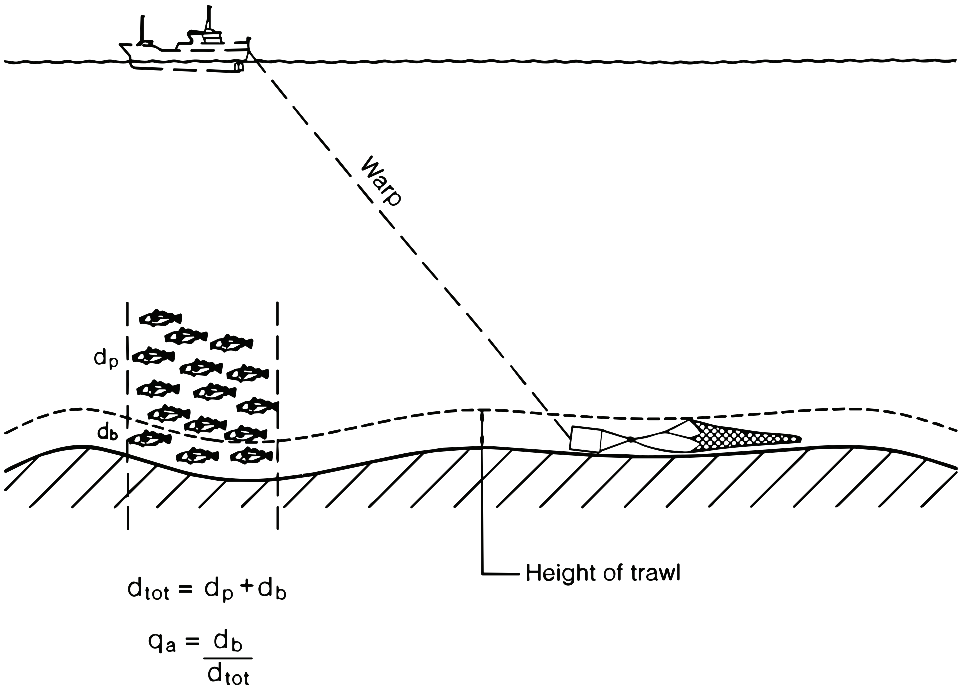

Fig. 3. Availability of fish to the trawl can be a function of fish above and below the headline of the sampling trawl in species such as cod. (Adopted from Godø 1994).

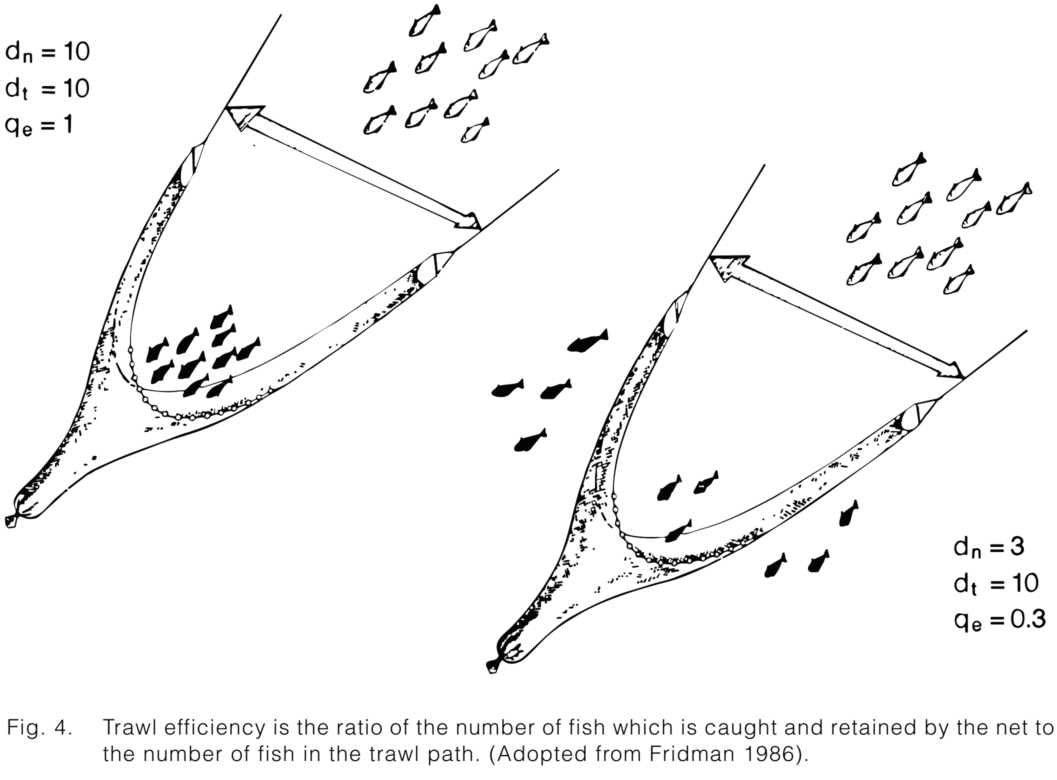

Fig. 4. Trawl efficiency is the ratio of the number of fish which is caught and retained by the net to the number of fish in the trawl path. (Adopted from Fridman 1986).

In trawl surveys within the NAFO area it is commonly assumed that $q_a = 1$, i.e. entire population of target species is in the survey area and accessible to the trawl, and $q_e = 1$, i.e. no size selectivity or escapement from the gear. Since both q_a and q_e are unknown and assumed to be constant coefficients (although both are probably less than 1), the stock size estimates become relative abundance indices. If both q_a and q_e could be precisely measured then absolute estimates could be derived. Assuming $q_s = 1$, then the total stock size (B) is estimated by:

$$B = D * A$$

where A is the area of the survey region.

Although recent studies have focused on interpreting survey catchability by examining changes in availability (q_a) in response to environmental changes and stock reduction, it is, nevertheless, important that we try to understand how these and other changes affect trawl efficiency(q_e).

Survey catchability

Many factors can affect survey catchability, chief among them are:

- the horizontal and vertical distribution of the target species in relation to the trawl, i.e. natural behaviour,
- behaviour of fish ahead of the trawl and in the vicinity of the trawl, i.e. vessel/trawl induced behaviour, and
- selectivity of the trawl.

Survey catch rates, i.e. average catch-per-tow, are considered proportional to the true stock density only if factors such as vertical and horizontal fish distribution, fish behaviour reactions to the trawl and the performance of the trawl are constant over time. Thus, within and between annual surveys, it is assumed that the:

- size and species selection is constant under various conditions,
- trawl performance remains constant under various conditions, and
- swept area of the trawl is known and is constant under various conditions.

Consequently, if any of these assumptions are invalid then the estimates are biased. Hence, the prime objective during the survey is to minimize bias and sampling variability by standardizing all operations and maintaining a constant catchability. Since we generally estimate relative abundance indices, a proportional bias is acceptable, provided that it is constant.

Trawl selection

Typically, in bottom trawl catches, the length distribution is biased towards larger fish due to size dependent selection of the trawl, i.e. it is the outcome of mechanical sorting by the various trawl components and differences in swimming speeds. Of primary importance in this mechanical sorting is the size of the footgear components and the mesh size of the trawl. Size and species dependent escapement under the footgear has been investigated for many survey trawls by rigging mini-trawl bags underneath the main trawl to catch escaping fish. Figure 5 shows the escapement of cod under the footgear of both Canadian survey trawls when equipped with similar 36 cm diameter rubber rockhopper gear. Here trawl efficiency (q_w) is calculated using the following equation:

$$q_w = M_c / (M_c + B_c)$$

where q_w represents the efficiency of the trawl defined as the area between the wing ends and the centre of the footgear, M_c = catch in the main trawl and B_c = total catch in the bag trawls. We assume here that all fish entering the trawl mouth area are caught either by the main trawl or the bag trawls. Size selection can also differ considerably between species e.g. more yellowtail flounder escape underneath the footgear than American plaice and more cod than haddock.

Age selection

In age-based assessment models, age data is derived from length of fish in the catch. Because escapement is strongly length dependent, estimates of age specific selection values will vary in accuracy from year to year if changes in growth, i.e. mean length-at-age, occur. For example, using the selection

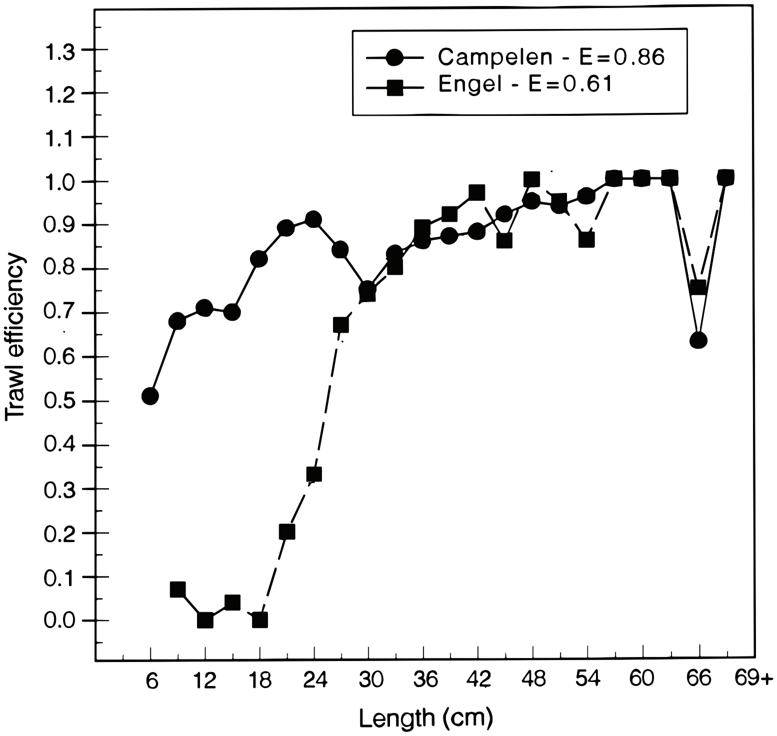

Fig. 5 Escapement of cod underneath the footgear of the Campelen 1800 shrimp trawl and the Engel 145 Hi-Lift otter trawl used in the Canadian bottom trawl surveys off Newfoundland. (Walsh and McCallum; unpublished data).

curve for the Engel survey trawl in Fig. 5, if the mean length of age 2 cod decreased from 21 cm (efficiency = 20%) to 18 cm (efficiency = 1%) then subsequent errors would occur in estimates of abundance-at-age and prediction of year-class strength coming into the fishery. Periodic changes in growth will affect age selection and if large enough could invalidate the reliability of the time series unless conversion factors are derived. This has been demonstrated in the northeast Arctic cod time series. Variations in the efficiency of survey trawls can reduce the accuracy and reliability of trawl data when these data are used in acoustic surveys to identify acoustic targets or used in species-interaction and some multi-species assessment models. The quality of survey trawl data, as representative of the population abundance, size and composition, should be critically examined in relation to the demands of these various models.

Diel selection

Diel variation in light intensity will also influence selectivity. For example, in Fig. 6, the efficiency of the Canadian Engel survey trawl in catching yellowtail flounder is higher at night than during the day, because of a reduction in gear avoidance at night. A similar pattern was evident for American plaice but the opposite pattern was seen in cod. This bias in efficiency could seriously invalidate a time series if not accounted for in the station allocation scheme used in the stratified random design. For example, in yellowtail flounder, if there is a higher proportion of night tows allocated in one survey year and a higher proportion of day tows in another, then the abundance and recruitment indices would be biased in opposite directions. This can be minimized by temporal stratification of number of fishing sets, i.e. a 50:50 proportional allocation of day and night sets within each strata, before the start of the survey. For tuning VPA's one could also time-partition the survey data into day and night indices and choose the one which has less sampling variability.

Trawl geometry and performance

Generally the variance around the average catch-per-tow is assumed to reflect changes in abundance and does not account for changes in catchability resulting from size and species specific fish behaviour. Fish behaviour, both natural and trawl induced, can confound the interpretation of catchability data. A

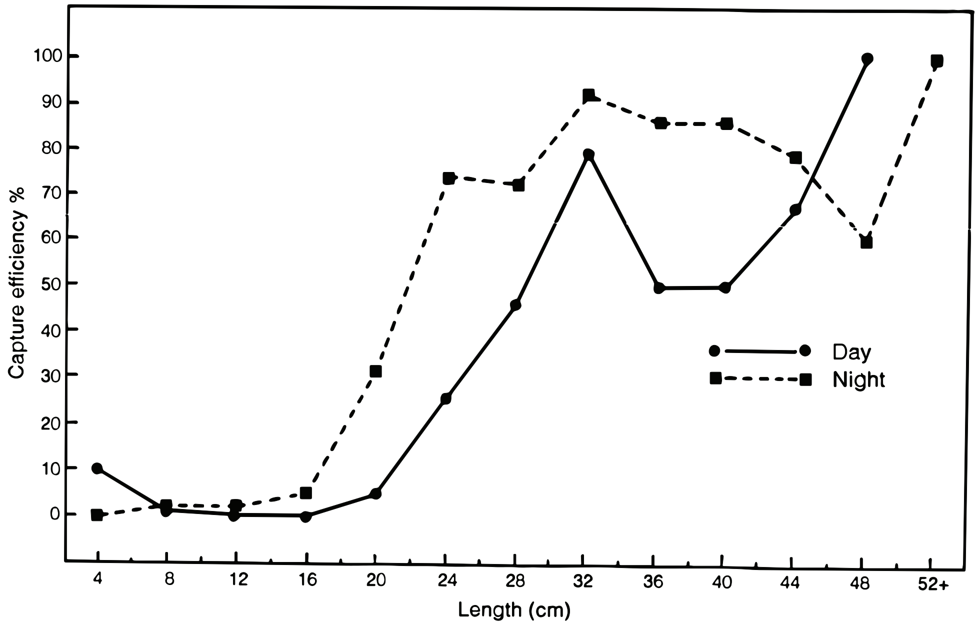

Fig. 6. Diel variation in trawl (catching) efficiency for yellowtail flounder derived from catches using an Engel 145 High Lift otter trawl. (Adopted from Walsh 1991).

major source of uncertainty in trawl surveys is the effect of changes in catchability on estimates of abundance due to changes in trawl geometry and performance. Variations during construction, repairs, deployment, retrieval and actual fishing practices can affect trawl geometry and performance efficiency. These can be minimized by rigorous standardization of protocols. The recent use of acoustic trawl monitoring sensors has shown that both trawl geometry and performance are mainly affected by towing speeds, water currents, bottom type, poor bottom contact, insufficient warp (scope) ratios, sea state and weather. Fish in front of the trawl will react to the instability of the trawl and thus catchability will vary. Biases created by any of these factors can affect the accuracy of the survey estimates. For example in Fig. 7, both door spreads and wing spreads are below their respective average spreads when the trawl is towed against the current (north) and above the average spread in tows which are with the current (south). Swept area will also be affected in a similar manner.

Swept area

Survey abundance indices are primarily calculated using a swept area model, i.e. a constant wing spread is used and multiplied by constant tow distance. This assumes that swept area within and between surveys is constant. In reality, this is not the case because trawls are flexible structures which change shape under various conditions and thus violate the constant sampling unit assumption. For example as seen in Fig. 8, the shape of the trawl in deep water is more collapse than in shallower water due to differences in trawl door spreads.

If a fixed wing spread is used in the model, then the swept area will be underestimated in deeper waters and, correspondingly, the abundance will be overestimated, with the opposite trend in shallow waters. Since we are dealing with relative indices of abundance, this proportional bias in catches and age (length) composition may be acceptable as long as there is no change in depth distribution of the stock or age classes. In recent years, some stocks in the NAFO area, e.g. American plaice, have shown a shift to deeper water, and depending on the magnitude of this change and the temporal and spatial scales, the fixed wing spread model would lead to an overestimate of the abundance in deep water and reduce the reliability of the time series. A similar change in size (age) depth distribution could confound interpretation of recruitment and mortality estimates of various year-classes based on swept area.

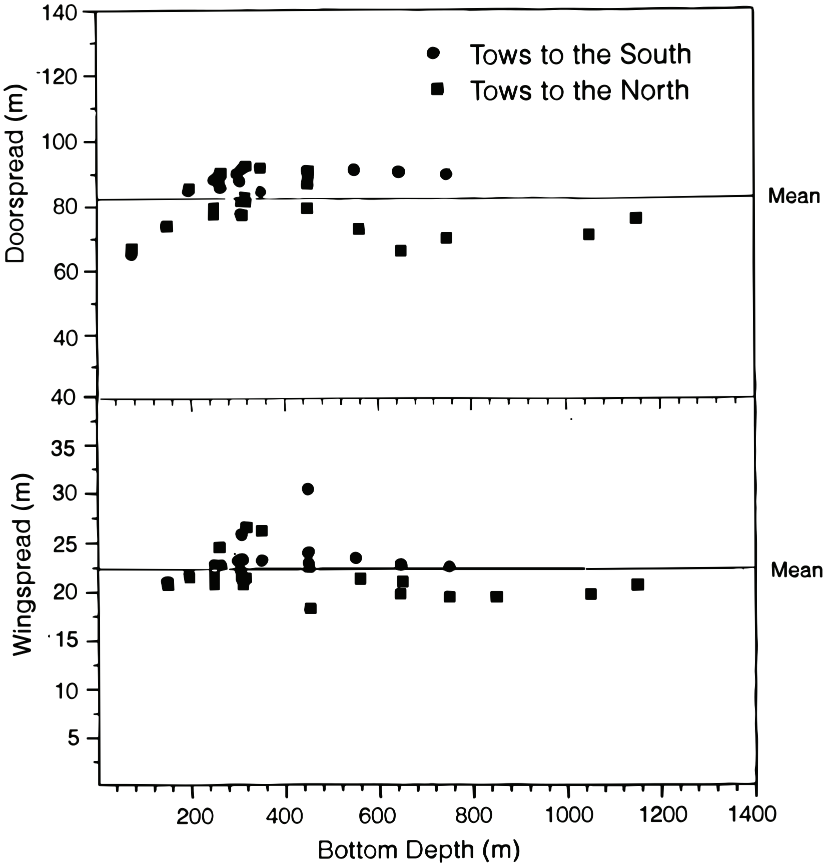

Fig. 7. Changes in door spread and wing spread of the Engel 145 survey trawl aboard the FRV *Gadus Atlantica* during tows north against the current and the reciprocal tow at the same station heading south with the current. (Adopted from Walsh and McCallum 1995).

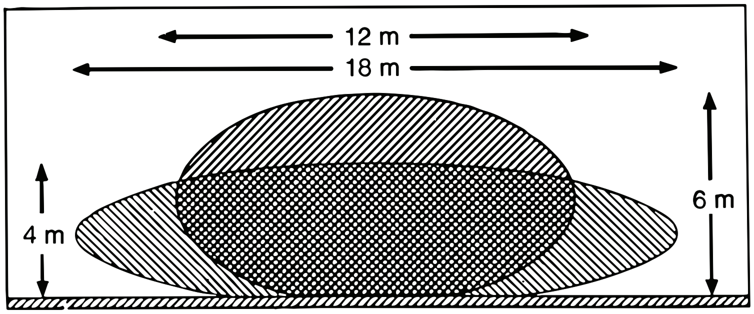

Fig. 8. Difference in trawl geometry of the Campelen 1800 shrimp trawl used in Norwegian bottom trawl surveys of the Barents Sea at depths of 50 m and 450 m. (Adopted from Godø and Engås 1989).

If trawl geometry data are available, the survey indices can be re-calculated based on a varying swept area model. Table 1 shows a comparison of the results of a constant wing spread model with a model that incorporates average wing spreads at 100 m depth intervals. Here the constant swept area model underestimates the younger ages of northeast Arctic cod (1–3 years) in the survey area because of a size (age) dependent depth distribution.

TABLE 1. Comparison of standard swept area indices of Barents Sea cod derived from a fixed wing spread model (I) with those indices corrected for trawl width variation by using a varying wing spread model (II) at different reference depth zones. Division (%) represents deviation from stanard indices. (Adopted from Godø and Engås, 1989.)

	Age							
Depth	1	2	3	4	5	6	>7	Total
(A) Model I: Standard indices								
0 – 100	12.9	79.9	54.9	14.1	1.8	0.8	0.1	164.5
100 – 200	10.4	31.3	12.8	6.5	1.5	1.5	0.5	64.5
200 – 300	3.4	17.6	4.0	3.3	1.3	1.9	0.5	32.0
300 – 400	0.3	2.3	1.6	2.6	1.2	1.9	0.5	10.4
>400	0.1	1.0	1.0	1.5	0.8	1.5	0.4	6.3
Total	27.1	132.1	74.3	28.0	5.6	7.6	2.0	277.7
(B) Model II: Corrected indices								
Reference depth zone 0–100 m WS_k = 12.2 m								
0 – 100	12.9	79.9	54.9	14.1	1.8	0.8	0.1	164.5
100 – 200	8.5	25.5	10.4	5.3	1.2	1.2	0.4	52.5
200 – 300	2.5	13.0	3.0	2.4	1.0	1.4	0.4	23.7
300 – 400	0.2	1.6	1.1	1.8	0.8	1.3	0.3	7.3
>400	0.1	0.7	0.7	1.0	0.5	1.0	0.3	4.2
Total	24.2	120.7	70.0	24.6	5.3	5.7	1.5	252.0
Division (%)	-11	-9	-6	-12	-19	-24	-25	-9
Reference depth zone 200–300 m WS_k = 16.5 m								
0 – 100	17.4	108.1	74.3	19.1	2.4	1.1	0.1	222.5
100 – 200	11.4	34.4	14.1	7.2	1.7	1.7	0.6	71.0
200 – 300	3.4	17.6	4.0	3.3	1.3	1.9	0.5	32.0
300 – 400	0.3	2.2	1.5	2.5	1.1	1.8	0.5	9.8
>400	0.1	0.9	0.9	1.3	0.7	1.3	0.4	5.6
Total	32.7	163.2	94.7	33.3	7.2	7.8	2.0	340.9
Division (%)	21	24	28	19	10	2	1	23
Reference depth zone 400–600 m WS_k = 18.4 m								
0 – 100	19.5	120.5	82.8	21.3	2.7	1.2	0.2	248.1
100 – 200	12.8	38.4	15.7	8.0	1.8	1.8	0.6	79.1
200 – 300	3.8	19.6	4.5	3.7	1.4	2.1	0.6	35.7
300 – 400	0.3	2.4	1.7	2.7	1.3	2.0	0.5	10.9
>400	0.1	1.0	1.0	1.5	0.8	1.5	0.4	6.3
Total	36.4	181.9	105.6	37.2	8.1	8.7	2.2	380.1
Division (%)	34	38	42	33	22	14	12	37

Although wing spread is commonly used in the swept area model, door spread is probably more representative of effective swept area than wing spread because of the auditory and visual herding stimuli of doors, sweeplines and sand clouds which herd fish towards the net. For example, if sweeplines are lengthened, causing the door spread to increase, higher catches of cod and haddock can result. Table 2 illustrates a comparison of Scotian Shelf cod indices estimated using a fixed wing spread in the swept area model (CI) and re-calculated indices derived from a varying door spread model (VI). In this case there is a greater reduction in the estimates of older cod using door spread. This is due to the fact that older fish are distributed in deeper water, i.e. increased door spread with depth in the fixed model would overestimate the abundance indices. It is noteworthy that during the two time periods (1970–82 and 1983–92) there appears to have been a shift in depth distribution even though the average survey depths were similar (see Clarke 1993).

It is obvious that trawl width variability can affect survey indices, however, in the few attempts that have been made in comparing adjusted and standard swept area indices, the CVs still remain high because of the typical patchy distribution of many groundfish species. However, this does not imply that modelling variation in swept area should not be used. Intuitively, the more relevant data that can be incorporated into the assessment, the more confident we should be about advising managers of our best estimate of the stock size. For example, in Table 3 the vessel survey indices of northern cod, NAFO Div. 2J and 3KL, derived using two vessels are overestimated (combined overestimate is 37%) because the standard wing spread used in the swept area model is unrealistically low when compared to that measured during the surveys. Re-adjustment of the time series with the new wing spread would not change the overall time series trend, however, this bias in the estimates of abundance (and recruitment) could be critical if a management decision to close or re-open a particular fishery depended solely on survey trawl data.

TABLE 2. Ratio of constant swept area indices (CI) to varying swept area indices (VI) for Scotian Shelf cod.

Age	Vessel 1 1983–92	Vessel 2 1970–82
1	1.11	1.16
2	1.13	1.18
3	1.14	1.21
4	1.19	1.22
5	1.22	1.23
6	1.22	1.23
7	1.21	1.25
8	1.19	1.23
9	1.22	1.27
10	1.18	1.30

(Adopted from Clarke, 1993).

TABLE 3. Differences in assumed standard mean wing spread and calculated mean wing spread of the Canadian Engel 145 Hi-Lift survey trawl aboard the two survey vessels used in the annual surveys of northern cod, NAFO Div. 2J3KL.

Wing spread	Width (m)	% Overestimated indices
Standard	13.7	–
Vessel 1	22.2	39
Vessel 2	19.8	31

Adopted from Walsh and McCallum, MS 1995.

Effect of tow duration

The distance trawled is the second variable in the swept area model and is also generally assigned a fixed value based on a known distance travelled during a fixed tow duration, e.g. a trawl will travel 1.75 nautical miles during a 30 min tow using a towing speed of 3.5 knots. Generally, the start of a tow is recorded when the brakes on the trawl winches are applied, even though there is evidence to suggest that the trawl settling time to the bottom in deep water can exceed 10 min. When that occurs, the actual tow distance is far shorter than the target value and the swept area estimate is biased. In Fig. 9, the variability (Trips H037 and 038; A306 and 307) in distance trawled from the target of 1.75 nm is common within and between Scotian Shelf trawl surveys and can be controlled (Trips N123 and 124) by introducing standardized vessel speed protocols.

Typically, tow duration in groundfish surveys are 30 or 60 minutes in length. Recently, in the Canadian surveys of NAFO stocks off the coast of Newfoundland the tow duration time was reduced to 15 minutes from 30 minutes. Figures 10 and 11 show that shorter tows are just as efficient as longer tows for many species of gadoids and flatfish, and similar results were obtained in Norway and the United States. When switching to a 15 min tow, it becomes more critical to accurately determine when the trawl reaches bottom. Here the active use of acoustic trawl instrumentation determines trawl bottom touch down, start of tow, end of tow and gear malfunctions. This will minimize variation in tow duration and reduce the number of "bad tows", which have been known to range up to 23% in some surveys. With the use of accurate navigational aids such as DGPS exact tow distances can be computed. Together with estimates of trawl width, the exact area sampled by the gear can be quantified on a tow by tow basis thus reducing biases in the area swept by the trawl.

The effect of fish density

In commercial CPUE data, the catchability coefficient q is inversely related to population abundance. Recent studies have suggested that in scientific surveys, trawl efficiency is directly related to abundance of fish in the trawl path, i.e. smaller numbers of fish led to an increase in gear avoidance. For example, in Fig. 12, derived from the bag trawl escapement experiments, the trawl efficiency increases with density of cod in the trawl mouth. Table 4 shows the catch-tow frequency of northern cod at low stock size in the 1993 fall survey. Here it appears that the stock is comprised of small numbers of individual cod distributed

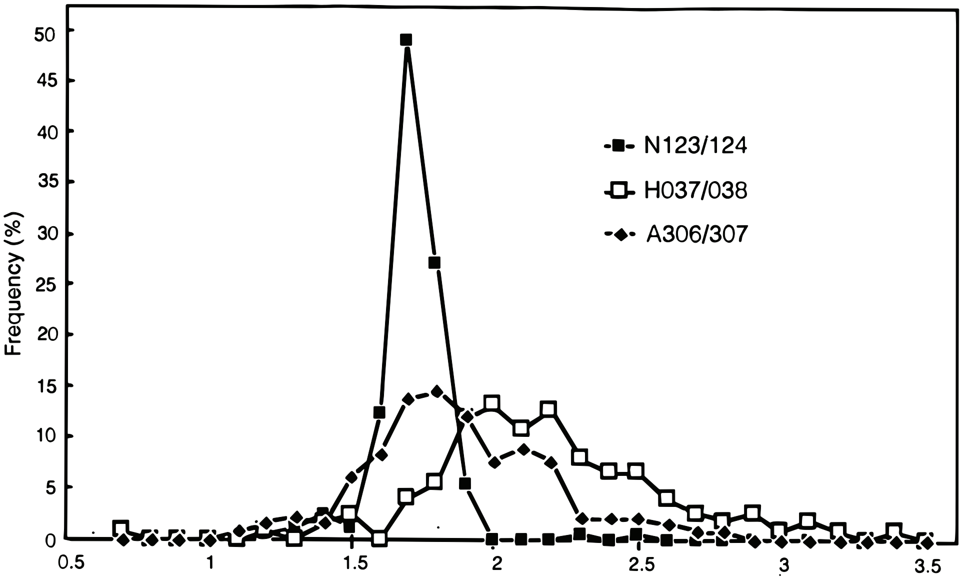

Fig. 9. Frequency of tow distances during 30 min tows before (H037/038; A306/307) and after (N123/124) introduction of standardized vessel speed control protocols. (Adopted from Koeller 1991).

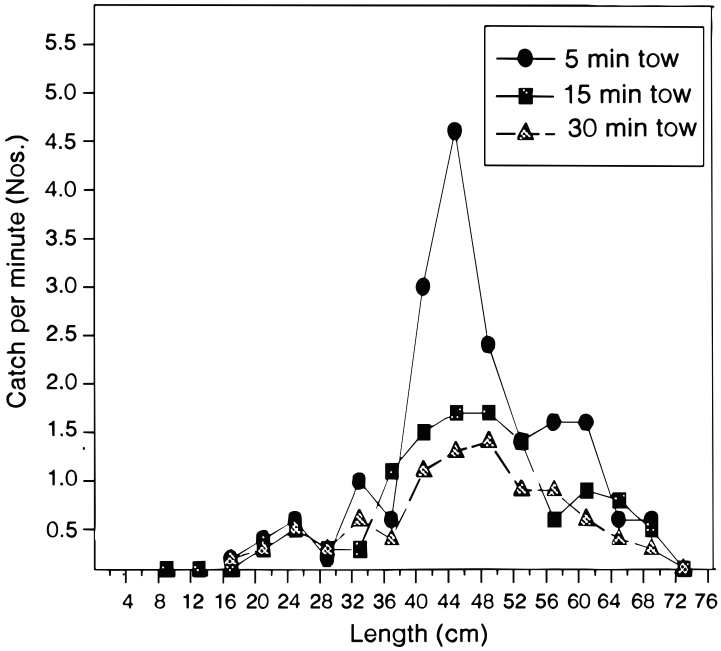

Fig. 10. Effect of tow duration on *CPUE* of American plaice using the Engel 145 survey trawl. (Adopted from Walsh 1991).

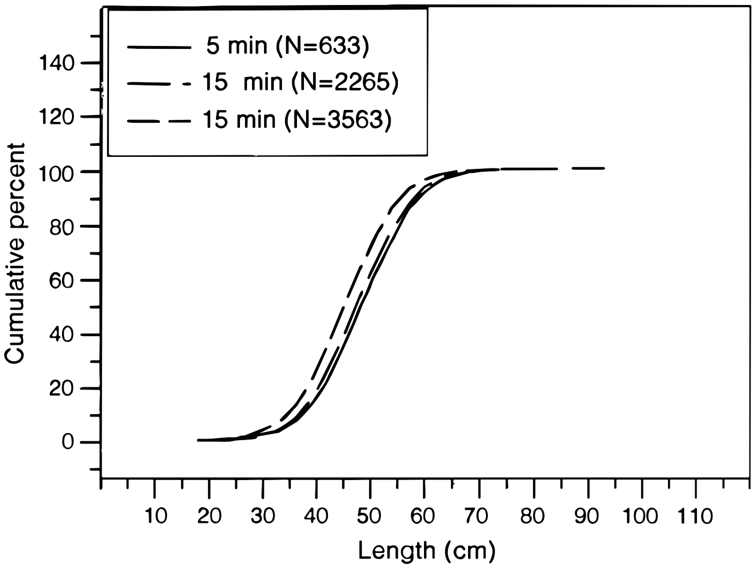

Fig. 11. Effect of tow duration on length composition of cod in catches of the Engel 145 survey trawl. (Walsh, unpublished data).

throughout the survey area. The density estimates can then be expected to be biased downward because of this decrease in trawl efficiency. If this trend in stock behaviour continues over several years, it will affect the accuracy and reliability of the time series when compared to other years when the stock size was larger and distribution was more patchy.

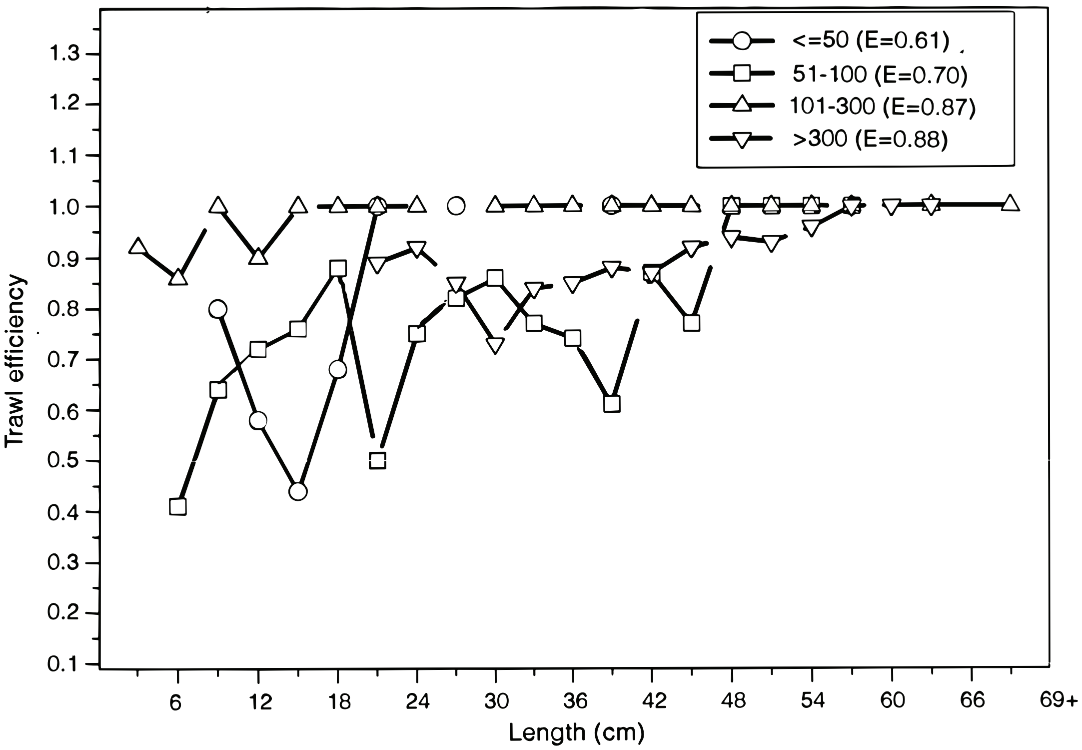

Fig. 12. Effect of density on trawl efficiency of cod derived from bag trawl escapement experiments. (Walsh and McCallum, unpublished data).

TABLE 4. Frequency of the number of tows with catches of cod in each category.

NAFO Area	< = 50 cod	51–100 cod	101–300 cod	> = 300 cod
2J	105	0	0	0
3K	160	0	0	0
3L	149	1	3	1
Total	414	1	3	1

Source: 1993 Canadian autumn survey of Northern cod.

Controlling trawl geometry, performance and swept area

As seen above, the accuracy of measuring the two components of the swept area model, tow distance and wing spread, are possible with the correct instrumentation which is widely available. Although modelling variation in trawl width has only increased the level of precision of survey estimates by 5%, using measurements of trawl width and tow distance variations into the calculation of swept area estimates should decrease some of the bias in swept area estimates.

There are also other approaches to improving swept area estimates. Figure 13 and Table 5 illustrates a Norwegian method of standardizing trawl width variation by physically restricting door spread with a rope placed ahead of the trawl doors to minimize the depth dependent trawl width variation. The method of rope attachment is quick and easy. Paired tows shown in Fig. 14 illustrates that there is little difference in length composition of trawl catches of yellowtail flounder in a restricted trawl and unrestricted trawl. Similar results were obtained for cod, American plaice, skate, Greenland halibut and redfish. By minimizing

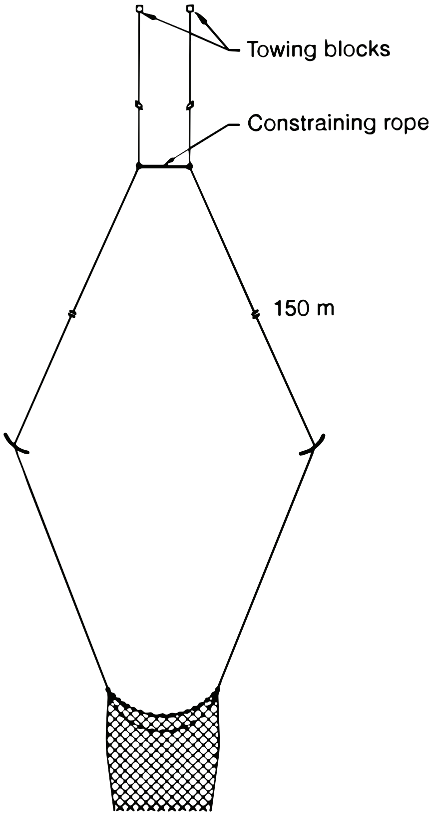

Fig. 13. Controlling trawl door spread using a rope strung 150 m ahead of the trawl doors. (Adopted from Engås and Ona 1993).

TABLE 5. Comparison of the geometry of the Canadian Campelen 1800 survey trawl with the door spreads restricted and unrestricted from alternate tows in a depth of 43 to 1 244 m. CV = coefficient of variation expressed as a percentage.

	Unrestricted			Restricted		
	Hauls	$\bar{x}$	CV	Hauls	$\bar{x}$	CV
Doorspread (m)	41	51.9	13	41	45.1	7
Wingspread (m)	40	15.5	7	41	14.3	9

Walsh and McCallum: unpubl. data.

the depth-dependent variation in swept area, the variance around average catch-per-tow (or biomass indices) should reflect primarily changes in abundance. One other major advantage of the restrictor rope is that it may be used to standardize fishing power when two or more vessels are used in the annual survey.

Absolute abundance indices

In order to estimate absolute abundance indices accurate measurements of availability (q_a) and trawl efficiency (q_e) are needed, i.e. catchability. Acoustic instruments can be used to provide the vertical

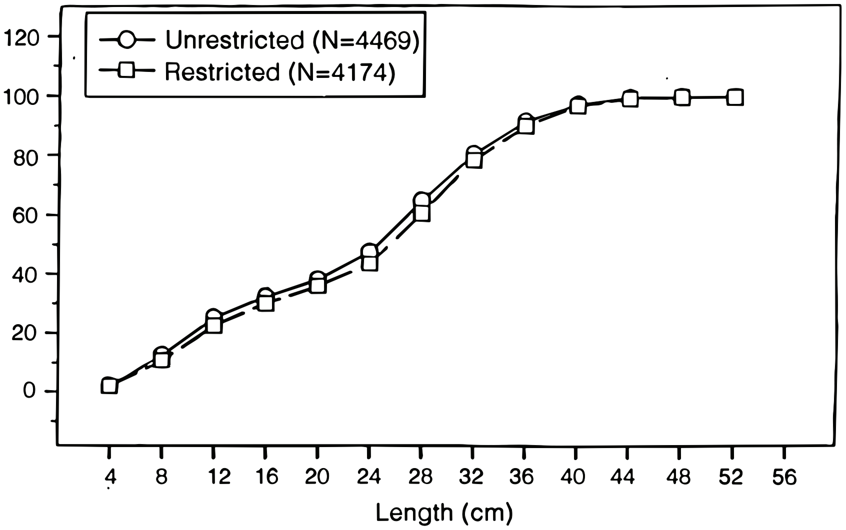

Fig. 14. A comparison of the length frequency of yellowtail flounder in catches of the Campelen 1800 shrimp trawl with restricted *versus* unrestricted door spread. (Walsh and McCallum, unpublished data).

component of q_a but may not be able to accurately resolve the horizontal component. There has been some success at measuring trawl efficiency using various techniques such as acoustic tags, submersibles and underwater video and depletion studies. Although these techniques have contributed to our knowledge of trawl-induced behaviour, most are costly not readily adaptable or applicable to other survey trawls or species.

Recently, the focus of some studies in Norway, Australia and United States has been on mathematically modelling the behaviour of fish in the three zones of trawl influence in an effort to improve on swept area estimates and absolute abundance estimation.

Summary and Conclusions

- Estimates of abundance from trawl surveys generally have large variances generated by fluctuations in spatial distribution, catchability, environmental conditions in the survey area or ecosystem and through the interaction of any one of these variables with the other.
- Although a survey is generally designed to minimize the effects of catchability through allocation of effort and survey coverage, less attention is directed towards sampling trawl variability. Standardization of fishing protocols are assumed to minimize differences in trawl performance and the survey design is expected to average out the effects of vessel noise, size, species, light intensity, tow duration, depth, and density on catchability and hence swept area estimates. The validity of this assumption is highly questionable.
- Many of the assumptions we make about our sampling tools are invalid and our survey estimates are biased as a result. A proportional bias in our estimates, however, is acceptable providing that it is constant. When the bias of the survey estimate is not consistent from year to year due to changes, e.g. in fish growth or catchability brought on by environmental changes, the quantification of the accuracy of an abundance index is difficult and this can reduce the validity of the time series.
- This review does not conclude that existing survey data are useless but underlines the necessity of incorporating studies to examine and account for potential errors in estimation of stock size and recruitment that are contributed by the sampling trawl. Generally, variances around abundance indices are high so that many biases affecting their accuracy in estimating stock size and recruitment may not invalidate the index.

- Coinciding with the recent severe reductions in stock size of many species in the NAFO area, there is evidence of changes in stock behaviour. These changes could affect availability and trawl efficiency and result in misleading trends in the time series and serious problems in assessment of the resource.
- Survey indices are still treated as relative abundance estimates because the shortcomings of survey design and estimation of sampling trawl efficiency have not been resolved. Given the enormous amount of resources and costs to conduct annual surveys and the fact that those survey indices may be the only source of information on which to base management advice then greater precision and accuracy in estimating stock size and year-class strength are highly desirable. This should be a continuing process.

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