Some Technological Aspects of the Norwegian Tuna Purse Seining Fishery

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INTRODUCTION

Purse seining for tuna on a large scale has in recent years been developed on the Pacific coast of the United States. Although the purse seine technique was introduced in the previous century and has been applied for catching tuna species both in Japan and the United States for several years, this gear has until recently played an unimportant part in the tuna fisheries of the world. The success in the later years of the U. S. purse seiners converted from tuna clippers has been described by McNelly (1961). According to McNelly the new fishing method was developed so rapidly that it attained the character of a revolution in the fishery. As the primary causes for this development, McNelly points to (1) the adoption by the fishing fleet of synthetic twines, (2) the advent of the Puretic power block, (3) the use of aircraft in locating fish, and (4) possible favourable oceanographic conditions influencing availability of fish.

In the present paper an account of the development of the Norwegian tuna fishery is given, including a brief description of the purse seine method used at present, and a consideration on its efficiency compared to the American technique.

THE DEVELOPMENT OF THE NORWEGIAN TUNA FISHERY

The bluefin tuna (*Thunnus thynnus* L.) is the only tuna species occurring regularly in Norwegian waters. The fishery takes place from the beginning of July to the middle of October. Only adult tuna are caught, ranging from 30—400 kg (Hamre, 1960).

Up to 1920, Norwegian fishermen caught tuna with angling gear and hand harpoon. These gears were not very efficient, and the catch was quite insignificant. It was obvious that with the available gears the tuna stock could only be poorly exploited by the Norwegian fishermen, and in

the late twenties intensive experiments to improve the methods of catching tuna were executed. As a first step the hand harpoon was modified to be fired from a gun, and the tuna harpoongun resulted in the first regular tuna fishery in Norwegian waters. According to Hanson (1958), nearly 200 small boats were hunting tuna on the Norwegian west coast during the late twenties, but the yearly catch amounted to only about 100 tons.

Fig. 1. Norwegian bluefin tuna catches 1930—1962 in 1,000 tons of gutted weight.

It required, however, a very high degree of marksmanship to hit this swift and rowing game fish, and from a commercial point of view the harpoon gun fell short of expectations. It was realized that other ways had to be sought for a rational utilization of the tuna resources, and it seemed natural to explore the possibilities of the purse seine technique. The idea of catching tuna with purse seine had been worked upon since the late twenties, but the experiments executed before the last World War had been rather discouraging. The difficulties were to construct a net which could hold the fish and at the same time be managable for fishing operation. It took about twenty years to work out the problem of combining necessary strength with sufficient net size, but the successful results obtained in the late forties caused a rapid expansion in the Norwegian tuna fishery (Fig. 1). Actually, what led to the final solution of the technical problems involved in constructing the tuna purse seine was the significant observation that the bluefin try to avoid net walls irrespective of whether the meshes are small or large and the twine flimsy or heavy, at least within very wide limits.

DESCRIPTION OF THE NET

The Norwegian tuna purse seine is an one-boat net and consists of two main parts, the wing and the bunt with a transition section in between (Fig. 2). The wing, which constitutes the longest part of the net, is made of very light material as its only function is to make it possible to encircle the fish schools. In the bunt, which is the final section left in the water after pursing and hauling in, the twine is considerably heavier, having sufficient strength to prevent the tuna to penetrate the webbing when drying up the fish.
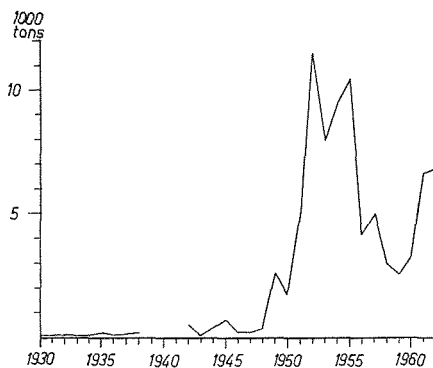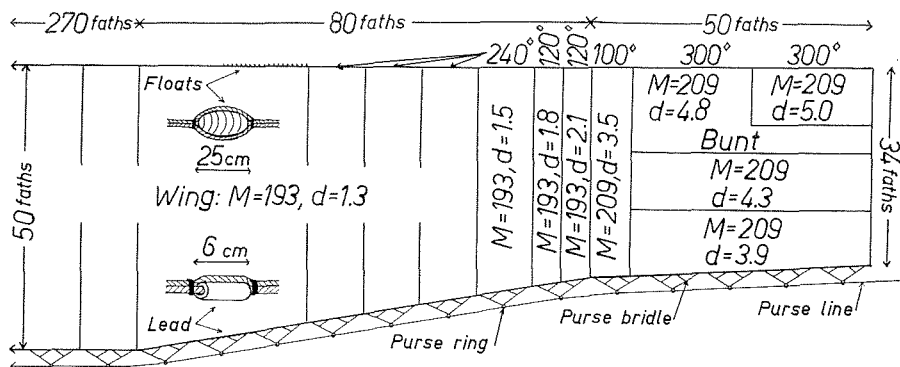
Fig. 2. Diagrammatic presentation of Norwegian tuna purse seine. ⟨⟩: meshes, M: mesh size, d: diametre of twine (in millimetres).

The wing is constructed by lacing together vertical strips of 240 meshes each. These are laced to the cork- and leadline selvedge strips which is hung-in about 60 % to the corkline, and some percent less to the leadline. In the first nets the webbing was made of hemp, which was later changed to cotton twine. At present, the fishermen are on the point of changing from cotton to nylon. In most of the nets in use the bunt is made of nylon, while cotton twine is still used in the wing.

The cork- and leadline are made up of double 12 mm diameter terylene ropes. Plastic floats are laced in between the corkline ropes. 12 mm terylene rope is also used for purse-ring bridles, one pursering for every 10 fathoms leadline is the usual ring density. The lead-weight on a 400 fathoms net is about 1200 kg, including the purse rings. 10 mm diameter stainless steel wire serves as purse line.

Actually, the nets in use differ with respect to details of construction, especially regarding the size of the nets. The original tuna purse seines were about 200 fathoms long and 30 fathoms deep. Improvements in handling technique and net materials have, however, made it possible to increase the net size considerably and the average size at present is roughly some 400 fathoms long and 50 fathoms deep. The increase in net size has been most spectacular in the wing, and nets are frequently enlarged by adding some strips of webbing each year. The length of the bunt, which is now about 50 fathoms in most of the nets seems to be of sufficient size for catching the biggest tuna schools occurring in Norwegian waters. The maximum catch in one shot was 91.5 tons (71.2 tons gutted weight).

THE FISHING OPERATIONS

The boats used for tuna purse seining are of the conventional type of medium size Norwegian fishing boats, with pilot house and engine room situated in the stern. On the aft deck is made space for the purse seine. The boats have no refrigerating system, the fish being delivered immediately after catching. On the average the seiners are about 70 feet long, the speed ranging from 8 to 12 knots. Most of the boats are built of wood, but during recent years several steel vessels have been added to the tuna fleet.

The seine skiffs measure approximately 18 feet in length, having engines of some 20 horsepower. When searching for tuna, the skiff is towed by the seiner. An additional powered boat of similar size as the skiff assists in towing on the corkline when the net is shot in order to hold the net open. If the net closes in, the fish will penetrate the light webbing of the wing. This assistance boat is carried on the main deck of the seiner, and comes into use when making successful shots only. A special towing boat of some 40 feet in length operates together with the seiner. Such boats are called "helpers" (Norwegian: hjelper) and its main task is to keep the seiner square with the shot net and from being pulled into the center of the net by the pursing operation. Furthermore, the helper assists in spotting fish, keeping in continuous radio contact with the seiner. Thus the tuna operation units consist of 4 boats, with a crew of 10 or 11 men.

All seiners are equipped with echo sounders, and a few with asdic. These fish-detecting instruments have, however, so far been of secondary importance in locating tuna schools, the fish being caught only when
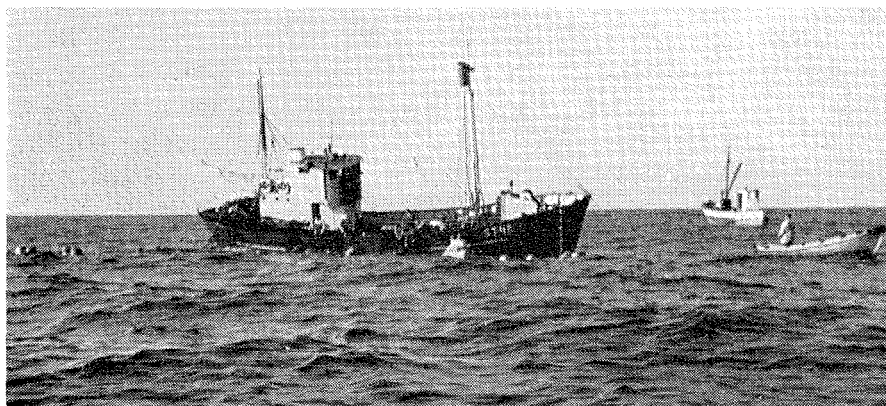

Fig. 3. Norwegian tuna seiner in action.

spotted at the surface. When operating on the tuna grounds, one or two mast-men, situated in a "crow's nest" at the top of the mast, are continuously searching for signs of tuna. Other members of the crew take positions at the roof of the pilot house, in the bow, or other suitable places for spotting fish. By radio contact with other tuna seiners the skipper keeps himself informed of the general situation with respect to fish concentration and the availability of the fish on various grounds.

The visibility of the tuna schools is closely related to the behaviour of the fish. Early in the season the fish are commonly observed swimming close to the surface, often without breaking the surface level. Under such circumstances the only tuna sign may be some rippling on the water or a little change in the colour of the sea. Using an American expression, such schools may be termed breezing schools (Norwegian: stripeflak). It requires a high degree of observation faculty to locate a breezing school, and the fishermen which are clever in spotting tuna, have great advantages in the competition on the tuna fishing grounds in the early season when fish spotting constitutes a very important part of the operation.

Later in the season the tuna changes its behaviour pattern, usually in late August, with the appearance of what the fishermen call a tuna knot. In the tuna knots the fish hunts its prey with great violence, making sea-spray as if it was a breaker. Very often such schools are marked by a cloud of gulls feeding upon the prey struck senseless by the tuna tails. In the case of tuna knots, the presence of the schools can be observed from several miles off.

When approaching a located school, the fishermen take their action stations for the shooting of the net. If the school is moving, the skipper must determine its speed and direction. This is important for the encircling maneuver. The net is shot at the maximum speed either in an approximate circle or in an elliptical curve, depending upon the movement of the school. To complete the encircling maneuver of the fish it often becomes necessary to use a net towing line and excess purseline. In such cases the fish is kept away from the open section of the net by fish scaring maneuvers of the skiff and the towing boat and by dropping calcium carbide into the sea where the fish have chances to escape.

The net is shot to starboard, and it takes about 3 minutes to shoot a 400 fathoms net. When the pursing is started, the helper begins its towing operations on the larboard side of the seiner. The skiff attaches a towing line to the corkline in the area between the bunt and the wing, and tows in the opposite direction of the helper in order to stretch the net out. To purse the net takes less than 10 minutes. If the shot is successful the boat on deck is put to sea for assisting the skiff in keeping the net open.

Up to 1960 the seiners used long rollers with mechanical drive for hauling in the net. These have now in most cases been replaced by hydraulic power blocks or by rollers of similar construction (Maloruller), which have reduced the hauling time of the net from about one to half an hour. When the light net has been hauled in, the towing on the net is stopped, and the skiff and the deck boat are laced on to the corkline. Big plastic balloon floats are attached to the webbing about one fathom under the corkline as an additional prevention against submersion of the corkline when drying up the fish. This is accomplished by using winch power, strapping aboard the heavy bunt webbing sectionally. Owing to lack of oxygen, the fish die quickly and are transferred to the seiner by using slings around the tails of the fish and hoisting them aboard in groups of 2 to 5 fishes.

THE SINKING VELOCITY AND THE OPERATION DEPTH OF THE NET

Employing a bathykymograph developed by Hester (1961), the sinking velocity and operation depth of a Norwegian tuna purse seine were tested in September 1962. This particular purse seine was of similar size and construction to that described above as a typical net. The instrument was attached to the leadline at the middle purse ring, and the result of the test is shown in Fig. 4 (N). The diagram shows the depth of the instrument at all times from entering the water until completion of the pursing operation.

From the time the instrument entered the water until pursing was started was 2 minutes. At that time the bottom of the net had reached a depth of 23 fathoms. The sinking velocity decreases very slightly before pursing but when this process starts the sinking velocity decreases rapidly, being reduced to zero after some two minutes pursing. The maximum depth reached by the instrument is $28\frac{1}{2}$ fathoms.

For comparison, corresponding tests of an American tuna purse seine are included in Fig. 4 (U_1 : U_2) (Hester, 1961). According to Hester these tests were made by attaching a bathykymograph to the leadline near half-net, the net measuring 435 fathoms in length and 43 fathoms in depth. The weight of the leadline including bridles and rings was about 7 tons (personal information). To shoot the half net took 1.5 minutes, which means that pursing starts about two minutes after the instrument entered the water. The two sets were made under different circumstances. The trace U_1 represents a set when wind and current were tending to drive the boat and the net apart, and U_2 when the boat
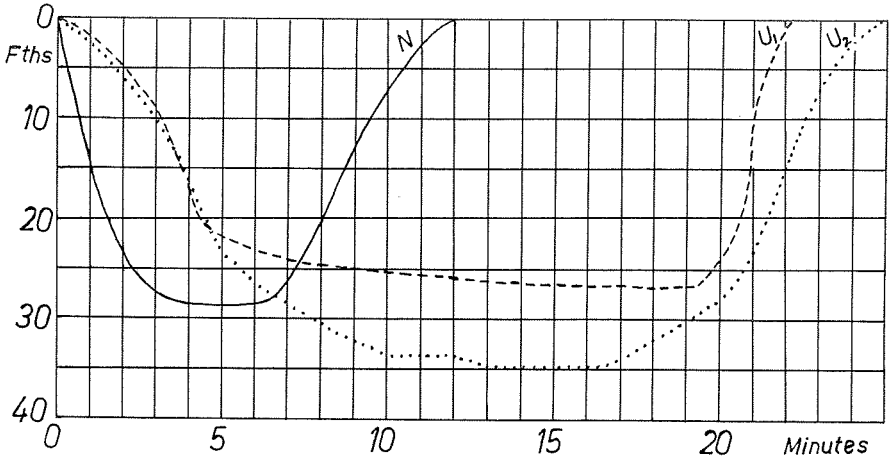
Fig. 4. Traces showing vertical movements of the leadline of tuna seines. N: Norwegian type, U: U.S.A. type. For further explanation see text.

drifted into the net. Concerning the conditions under which the Norwegian net was tested, the current and wind acted as in the case of U_2, but the helper prevented the seiner from drifting into the net.

From Fig. 4 it is evident that considerable differences exist between these two types of net with regard to sinking velocity and time used in pursing the nets. Although the "lead weight" per fathom of an American net is nearly 5 times that of the Norwegian one, the latter sinks with an average speed nearly 4 times greater in the time interval before pursing has been started. The time required to purse the Norwegian net is about half of that of the American one.

SOME THEORETICAL CONSIDERATIONS ON NET CONSTRUCTIONS

The size of a purse seine on the square of the net in action is determined by the length of the net, the depth, and the ratio of hanging. The length is usually given by the length of the corkline. The depth is either referred to as the number of meshes together with the mesh size used in the webbing, or it may be given as the depth of the net when the meshes are stretched vertically. The ratio of hanging may be expressed as the length of line divided by the length of stretched webbing. The ratio is termed the hanging coefficient (ϱ_1):

$$\varrho_1 = \frac{l_c}{l_w} = \frac{p}{100} \tag{1}$$

where l_c is the length of the line and l_w the length of the stretched webbing. p is termed the percent of hanging. A more commonly accepted expression of hanging a net is the ratio:

$$\frac{l_w - l_c}{l_w} \cdot 100 = P \tag{2}$$

P is termed the "percent of hanging-in", or the "looseness percent of hanging". From (1) and (2) it follows that $P = 100 - p$, i. e. P is the complementary value of p (Lusyne, 1959).

The effective depth of a purse seine depends upon, apart from the given depth, the hanging ratio of the webbing. If D is the given depth, i. e. the depth of vertically stretched meshes, one has:

$$D = n \cdot 2a \tag{3}$$

where n means number of meshes and a the length of the mesh bars. In hanging the netting to the corkline, the shape of the meshes depend upon the hanging ratio so that if 2φ is the angle between the mesh bars, the following equation is obtained (see Fig. 5):

$$\cos \varphi = \varrho_1 = \frac{100 - P}{100} \tag{4}$$

The height of one mesh is $2a \cdot \sin \varphi$, and multiplying by n gives the actual depth of the net (D'):

$$D' = n \cdot 2a \cdot \sin \varphi = D \cdot \sin \varphi$$

or

$$\sin \varphi = \varrho_2 \tag{5}$$

where $\varrho_2 = \dfrac{D'}{D}$; ϱ_2 may be termed the "actual depth coefficient" of the net. Since $\cos^2 \varphi + \sin^2 \varphi = 1$, it follows from (4) and (5):

$$\varrho_1{}^2 + \varrho_2{}^2 = 1 \tag{6}$$

This simple circle equation shows the relationship between the hanging coefficient and the coefficient of the actual depth. A graphical illu- stration of the equation is given in Fig. 6. Corresponding P-values are noted on the ϱ_1-axis.

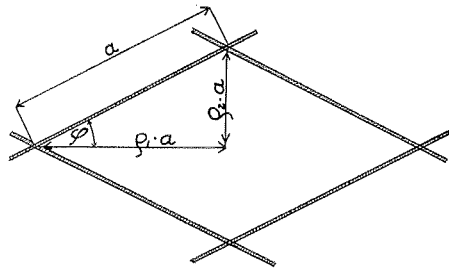The square of filtering area of one mesh is $2a^2 \cdot \varrho_1 \cdot \varrho_2$ (Fig. 5).

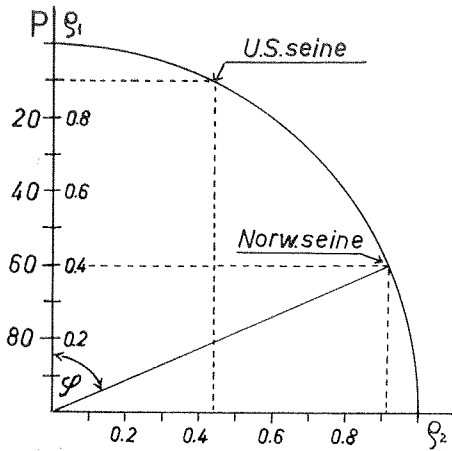Fig. 5. Mesh diagram. ϱ_1: coefficient of hanging, ϱ_2: coefficient of actual depth, a: mesh bar.

Fig. 6. Diagram showing the relationship between the coefficient of hanging (ϱ_1) and the coefficient of actual depth (ϱ_2). P denotes the hang-in percent, φ half the angle between the mesh bars.
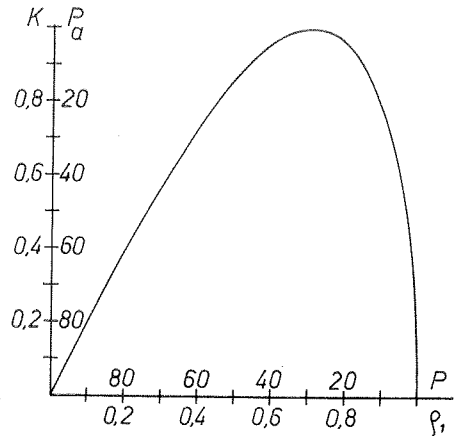
Fig. 7. Diagram of the filtering area of webbing. For explanation see text.

The filtering area (A) of a plane net, n meshes deep and n' meshes long is:

$$A = n \cdot n' \cdot 2a^2 \cdot \varrho_1 \cdot \varrho_2 \tag{7}$$

and from (6) and (7) is obtained:

$$K = 2\varrho_1 \cdot \sqrt{1 - \varrho_1{}^2} \tag{8}$$

where $K = \dfrac{A}{n \cdot n' \cdot a^2}$ is the ratio between the filtering area of a net with

hanging coefficient ϱ_1 and the filtering area of a net with square meshes $(\varrho_1 = 0.7071 , P = 29.3\%)$. K is termed the filtering coefficient of webbing. It equals 1 for $P = 29.3\%$ and decreases for higher and lower values of P. The variation in K as a function of ϱ_1 (or P) is shown in Fig. 7. The P_a values give the percent of area lost for P-values $\lesssim 29.3\%$

$\left(K = \dfrac{100 - P_a}{100}\right)$, and may be termed the "area looseness percent".

A purse seine in action undergoes a change in shape owing to the forces acting on the net during the operation. The stress of the leadline which cause the net to sink is transmitted through the netting along the mesh bars, the direction of which depend upon the shape of the mesh. Decomponating a force F acting along one bar, the horizontal (F_H) and vertical component (F_V) of the force are as follows (Fig. 5):

$$F_H = F \cdot \cos \varphi = F \cdot \varrho_1 \tag{9}$$

$$F_V = F \cdot \sin \varphi = F \cdot \varrho_2 \qquad (10)$$

The horizontal stress component of the weight put on the leadline is proportional to the hanging coefficient, and thus decreases with increasing P. The component causes a lateral movement in the flexible net, which has the same effect on the length/actual depth ratio as increasing P. This means that when the net is shot in a circle, the circumference of the net selvedges decreases (the lines make turns) but the net will gain depth proportionally to the increment in P, as illustrated in Fig. 6.

The change in shape caused by the pursing operation is far greater and more complicated than that caused by the horizontal stress component. During pursing the decreasing circumference of the bottom selvedge makes the net deeper, which contributes to make the bottom in the net. The curvature of the net wall is, however, influenced by several factors, the most important are the length/actual depth ratio and the depth in which the net is pursed. The latter varies with the sinking velocity and the speed of pursing (Iitaka, 1955).

The resistance of webbing to sea current has been studied by several investigators, and a recent review has been given by Kawakami (1959). According to Kawakami, the resistance (R) varies proportionally to the area of the webbing and approximately proportionally to the square of the current velocity (u):

$$R = c \cdot A \cdot u^2 \qquad (11)$$

where c is a coefficient depending upon the length and the diameter of the mesh bars, the twine, and the angle φ. c is found to be proportional to the area of the webbing projected on the plane perpendicular to the direction of the current. When the current is acting perpendicularly to the net plane, the value of c has its minimum for square meshes, $\varphi = 45°$, and increases for higher and lower values of φ.

DISCUSSION

The combination of a short but strong bunt with a long wing made of very light material has enabled the Norwegian fishermen to construct a tuna purse seine strong enough to hold a giant bluefin and at the same time be manageable for the fishing operation. The function of the wing is to encircle the fish and guide them into the bunt, in which the killing of the tuna can be executed. The catching principle is thus very similar to the technique upon which the tuna traps are founded. The wing corresponds to the guiding net of the traps, the bunt to the "death-chamber".

Before the nylon twine was introduced in the bunt, the fishermen had difficulties in handling the biggest catches, particularly in rough weather, and it happened that the webbing of the bunt was broken by the heavy weight, and the whole catch lost. With the change to nylon twine in the bunt this difficulty has been overcome. However, the greatest improvement in the catching efficiency of the net in recent years has been obtained by increasing the size and the handling speed of the wing section.

Actually, the size or filtering area of the tuna nets carried by the small Norwegian seiners are more than twice than that of an American net, owing to the higher hanging-in percent. According to McNelly (1961) the American tuna nets are hung-in about 10 %, which correspond to an actual depth coefficient (ϱ_2) of 0.44. For the Norwegian net ϱ_2 is 0.92 (Fig. 6). The American net tested by Hester (1961) has thus an actual depth of about 19 fathoms, its filtering area being approximately 8250 square fathoms. The corresponding figures of the wing of the net described in this paper are 46 fathoms (at half net) and 15500 square fathoms, the transition section included. Including the bunt, which is hung in about 38 %, the total filtering area of the Norwegian net becomes about 16,900 square fathoms. It should, however, be noted that due to the deformation of the nets in action, the American net will gain filtering area ($P < 29.3$ %), whereas the Norwegian net will loose area, probably very rapidly, as the pursing proceeds, owing to the high hang-in percent (Fig. 7).

As a matter of fact, 60 % hang-in is a very unrational hanging ratio. The loss of area when P equals 60 % is 26.6 % (Fig. 7), or about 5600 square fathoms in the wing and the transition section of the net shown in Fig. 4. For each percent increase in $P > 60$ % the increment in P_a is nearly 1.9 %. However, the deformation of the net, caused by the pursing operation which decreases the bottom selvedge mainly, makes the calculation of P_a more complicated than in the case of a plane net. It is, nevertheless, obvious that the pursing will decrease the filtering area proportionately to the hang-in percent of the bottom selvedge strip. An additional disadvantage is that the resistance coefficient of the webbing increases for P-values greater than 29.3 % (11).

Apart from size, the catching capacity of a purse net is mainly determined by the operational speed and the sinking velocity. The operational speed (shooting and pursing) decides the chanches of encircling, and the sinking velocity the chanches of preventing vertical escape. The time used to shoot the net has been reduced by introducing faster moving seiners, the average shooting speed is at present about 8—10 knots. With regard to the sinking velocity and the time of pursing, it becomes evident from Fig. 4 that the Norwegian seine leaves the fish a far lesser chance to

escape than does the American type. This is mainly a result of the difference in the design of the nets. With respect to the vertical movement of the bottom margin the most obvious reason for the fast sinking of the Norwegian net is the small resistance of the light webbing used in that net (11). Another factor which may influence the sinking velocity in disfavour of the American type, is the difference in P. It seems likely that for so small values of P as 10 %, the horizontal stress-component (9) is considerable even before the net is stretched out, so that a part of the "lead-power" contributes to the deformation of the net before it has reached its actual depth. This suggestion is corroborated by the variation in depth between the two traces U_1 and U_2 (Fig. 4). As the wind and current in the case of U_1 drove the net and boat apart, this should result in a considerable stress on the corkline in a direction opposite to the horizontal stress component of the lead-weight. The trace U_1 indicates that the net was stretched out in a depth of 20 fathoms, and taking into account the influence of pursing, it seems fair to conclude that no active F_H can be recognised. However, if the latter force is active before the net is stretched out vertically and the stress on the corkline is removed, this should result in a change in the sinking trace similar to trace U_2. According to Hester, it was also observed that towing with the skiff when the net was being laid out caused the bunt to sink more slowly. The towing with the skiff will result in a similar stress on the corkline as in the case of U_1. Both observations indicate that small P-values may reduce the sinking velocity of a flexible net.

The light webbing used by the Norwegians is also an important factor in reducing the pursing time. Another important factor favouring the Norwegian type is the smaller length/actual depth ratio. By model experiments with a Japanese sardine purse seine, Iitaka (1955) found that when pursing the net before it had reached its actual depth, the stress on the purseline was insignificant compared to what it was after this depth was reached or when the net was streched out. The excess webbing, as a result of the difference between the actual depth and the operational depth contributes to make the bottom in the net when pursed. As long as excess webbing is left, the sea current force caused by pursing is acting in the net plane mainly, and consequently the resistance against the movement is relatively low. As soon as the excess webbing is consumed, however, further pursing produce a resistance force component acting perpendicularly to the net plane and consequently increases the stress on the purse-line (11). For the same operational depth a shallow net such as the American one in which the length/actual depth ratio is 100 : 4.4, requires therefore much more power to be closed than does net of the Norwegian type where the ratio is 100 : 11.5,

even if they were made of the same material. In this connection it may be mentioned that in the Japanese tuna nets the length/actual depth ratio is about 100 : 13, using 20 % —30 % hanging-in (Takayama, 1962).

The most evident disadvantage of the Norwegian net construction is the low breaking strength of the webbing in the wing. It can only be used for catching fish species which shun a net wall, and it must be handled with the greatest care during the operation. In spite of the highest attention paid in removing things which may tear the light webbing, it happens that parts of the nets are broken during shooting and pursing. Sharks and other animals occurring together with the tuna often penetrate the net, making holes in the wing and the transition section. The operation requires high towing capacity because the greatest care must be taken in keeping the net open and in preventing the seiner from drifting into the net. Finally, this net construction does not allow separation of a big catch into batches, as can be done with a net construction as the American one (McNelly, 1961).

The object in choice of net design is to obtain the largest catching capacity of the net for the smallest coast of material and power requirement under actual fishing conditions. For the fisherman, an approach in the direction of a more rational gear involves a better income, and he has consequently been the driving force behind the development of the purse seine constructions and in the purse seining technique. Although the complexity of problems connected with the working pattern of a purse seine cannot be solved on a mathematical basis only, theoretical investigations on the behaviour of webbing may be a valuable tool. The calculation, for example, that more than 25 % of the webbing area in a Norwegian tuna purse seine seems not to be properly used, has unveiled a probable disadvantage in the net construction, and a more rational net may be obtained by changing the hanging ratio. This may also reduce the resistance of the net to current and motion caused by pursing (11). For keeping the actual depth unchanged, one can calculate that 15 fathoms of stretched meshes will have to be added to a 50 fathom deep net if the hung-in percent was reduced from 60 % to 30 %. However, the reduction in the hang-in percent will lead to changes in the stress components of the webbing [(9) and (10)]. How this may influence the working pattern of the net can only be found from experimental data.

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