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VIABILITY OF TAGGED PACIFIC HALIBUT

BY

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FOREWORD

The 1953 Convention between Canada and the United States for the preservation of the halibut fishery of the Northern Pacific Ocean and Bering Sea continued the conservation objectives of the three conventions which preceded it and in addition specifically required that the stocks of halibut be developed to those levels which will permit the maximum sustainable yield and that they be maintained at those levels. These objectives require accurate knowledge of the vital statistics of the population of Pacific halibut.

This report presents estimates of the survival of tagged halibut in the time period immediately following the tagging operation. With such estimates, parameters of the halibut population as determined from tagging studies can be made more precise.

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INTRODUCTION

Investigation of the Pacific halibut fishery by the International Pacific Halibut Commission has required extensive use of tagging for determining the interrelationships of the stocks, and to provide estimates of population size, and fishing and natural mortality rates.

In assessing the value of such estimates it is necessary to examine the basic assumptions involved in the tagging process and evaluate the errors inherent in the method. Such errors have been classified as belonging to certain types (Beverton and Holt, 1957; Ricker, 1958). This report deals with the Type A error of Ricker (Type I of Beverton and Holt), namely that which occurs over a relatively short period of time either at tagging or at the time of recovery.

REVIEW OF LITERATURE

Most of the halibut that have been tagged by the International Pacific Halibut Commission since 1925 have been taken with setline gear of the type commonly used in the North American Pacific halibut fishery. Tagging requires that the fish must first be hooked, remain attached to the gear for variable periods of time, brought to the surface from varying depths and removed from the water. They are then unhooked and held for attachment of the tag. Fish subjected to such stresses will sustain injuries ranging from very slight to critical, if not fatal.

Prior to being selected for tagging all fish are examined visually to determine the extent of injury and appraised according to various subjective criteria as to their potential for survival.

The probability of mortalities resulting from the tagging operation has long been recognized (Graham, 1928; Schroeder, 1930), but little direct effort has been made to evaluate the magnitude of such mortality. Thompson and Herrington (1930) state in regard to setline caught halibut:

> "The percentage returns obtained from the marking experiments must also be affected to some extent by the immediate mortality due to the hook injuries received prior to tagging, to bringing the halibut to the surface from varying depths, to absence from its native element, and to the handling it receives during the process of tagging."

They concluded from the high percentage recovery, and no apparent difference in recovery rate between various types of observable hook injury that little tagging mortality was present.

The only practical method for measuring tagging mortality is to retain tagged fish under some type of restraint so that observations can be made at frequent intervals. Mortalities occurring in such a group of confined fish may not be entirely typical of tagged fish released into the natural environment, but should furnish some useable approximation of the true magnitude of tagging mortality.

Except for experiments reported by Manzer (1952) on tagged English sole, few studies have been made with demersal species. Most of the earlier holding experiments have involved small pelagic round fishes such as the herring (Rounsefell and Dahlgren, 1933; Hart and Tester, 1937), sardine (Janssen and Aplin, 1945) and mackerel (Fry and Roedel, 1949; Sette, 1950). In all cases, substantial tagging mortalities could be demonstrated, though in some cases the results obtained could in part be attributed to the difficulties of maintaining the fish under physical restraint. Most of these authors noted that the significant portion of mortalities attributable to tagging occurred early in the holding period, usually within a week to ten days, and subsequently decreased. This was also found in the tagging of small troll-caught silver salmon (Milne and Ball, 1956) where a substantial mortality occurred, mostly early on the first day as a result of hooking, hauling in and handling when removing the hook.

Deaths have also been demonstrated in relation to excessive exertion, a condition that may well be of importance in any type of hook and line fishery where the fish remain attached to the gear for extended periods of time. Black (1958 a, b) summarizes the available literature regarding "hyperactivity" as a lethal factor in fishes for various aspects of fisheries management, including tagging, again pointing out that when mortalities do occur, they appear within a few hours immediately following the period of exertion. The possible seriousness of hyperactivity as a cause of mortality to hook and line caught fish has been demonstrated on various species of salmon (Parker and Black, 1959; Parker, Black and Larkin, 1959).

1958 EXPERIMENTS

LOCATION OF EXPERIMENTS

The 1958 experiments were conducted during May and June in Kitoi Bay, on Afognak Island (latitude 58° 11′ 30″ N., longitude 152° 21′ 00″ W.).

METHODS AND MATERIALS

With no information available pertaining to means of holding large demersal marine fishes, it was decided to use floating live-boxes to facilitate handling and observation of the fish.

Four live-boxes of varying dimensions (Table 1) were constructed of wire fencing materials, using 2″ x 2″ 14-gauge galvanized nonclimbable fencing for the sides and 1″ x 1″ 14-gauge galvanized Keyweld* fencing for the bottoms, all wire components being connected by means of hog-rings. A framework of ½″ galvanized pipe was placed under the wire bottom of each of the live-boxes to prevent sagging. The live-boxes were suspended from a styrofoam and plank frame, and the tops were sealed by means of a Fiberthin* cover which also shaded the enclosed area from direct sunlight.

A smaller non-floating live-box constructed of a 3/16-inch galvanized angle-iron frame, covered by 36-thread cotton seine netting, was placed in approximately 30 feet of water in the vicinity of the floating live-boxes. This sunken live-box allowed the fish to exist under somewhat more natural conditions though they were more crowded than in the larger floating units.

All halibut utilized in the experiments were taken by the chartered vessel *Commando* using commercial setlining methods. The tagged fish were placed in a

Table 1. Outside Dimensions and Surface Area of Floating and Sunken Live-boxes.

Live-box Type	Dimensions (Feet)	Area (Square Feet)
Floating	10 x 10 x 8	100
Floating	10 x 15 x 8	150
Floating	10 x 20 x 8	200
Floating	20 x 20 x 8	400
Sunken	8 x 8 x 3	64

* Trade name

6′ x 5′ x 3′ plywood box on deck and furnished with a constant supply of sea water supplied through a 1-inch rubber hose. During periods of bad weather the fish were subjected to a considerable amount of buffeting within the holding-box.

After each day's fishing, the vessel was positioned alongside a live-box, the Fiberthin cover was removed and the fish were lifted over the rail of the vessel and dropped approximately five feet into the water after which the cover was refastened.

RESULTS

It was found that the floating live-boxes were unsatisfactory despite their greater convenience for handling and observing the halibut. A number of fish escaped through openings between the bottom and sides of the live-box when the hog-rings were spread by constant motion and by halibut swimming into the wire sides. The most serious problem however, was serious abrasions on the fish, resulting from their lying on the wire bottom panels. This condition unquestionably was the major cause of most of the numerous mortalities that occured during the course of the experiments and completely overshadowed any actual tagging mortality. Fish placed in the stationary sunken live-box made of cotton webbing suffered no such injuries.

Notwithstanding the escapes and injuries resulting from confinement, there was a complete lack of mortalities until the 6th day following tagging. This was notable in view of the obviously detrimental and unnatural conditions to which the fish were exposed. Thus while these experiments could not be used to furnish any useful estimate of tagging mortality, they did indicate that short term mortalities of the type described by Black (1958 a, b) are probably not a serious problem in halibut tagging. The experiments also provided useful guidelines for designing subsequent studies.

1960 EXPERIMENTS

LOCATION OF EXPERIMENTS

The 1960 experiments were carried out in northern Hecate Strait at Butler Cove, a sheltered bay at the southern end of Stephens Island (latitude 54° 06′ 30″ N., longitude 130° 40′ 00″ W.) and in close proximity to productive halibut fishing grounds. The bottom sediments were primarily sand with an over-burden of mud and the sea floor was generally level. With maximum differences between high and low water in excess of 20 feet the depth range in which the live-boxes were located varied between 15-20 feet at low water to 35-40 feet at high water.

METHODS AND MATERIALS

The 1958 experiments indicated the need to eliminate all wire components and motion from the live-boxes. The new design adopted consisted of a 20′ x 20′ x 6′ framework made of ½″ galvanized pipe, 3/16″ galvanized steel plate corners, with pipe and wire braces at the top edge of the live-box to furnish additional structural support.

The side panels were covered by 18-thread continuous filament nylon seine netting having a 3¼-inch stretched mesh. The top was made of the same netting with one corner modified to provide an entry into the live-box. Netting was not required on the bottom as it was to be placed directly on the sea floor.

The live-boxes were assembled near the low tide mark, then floated by means of styrofoam floats and towed about 350 yards to the experiment site. The live-box was lowered to the bottom by block and tackle with one man at the surface and one diver. Once the live-box was positioned on the bottom, all floats were cut away and the weight of the live-box forced the pipe frame into the bottom sediments, effecting a complete closure. Figure 1 shows a completed live-box with all floats attached, prior to being moved into deep water.

Five live-boxes were constructed, all of identical size and construction, thus furnishing the same holding conditions for each group of fish retained during the viability studies.

Fish for these experiments were caught by the chartered setline halibut vessel *Sunnfjord* while engaged in tagging experiments off British Columbia and southeastern Alaska. All fish used in these experiments were caught and handled in essentially the same manner as in 1958.

Halibut were retained in a holding-box on deck from a minimum of 2 hours to a maximum of 15 hours. Though no unusually bad weather prevailed the fish were subjected to a certain amount of motion from the vessel rolling and pitching. Fresh sea-water was added to the holding-box at frequent intervals during times when fish were present. The numbers of fish carried in the holding-box varied from 10 to 36. They appeared equally viable at time of delivery to the live-box regardless of the size of the lot.

The experimental procedure called for holding groups of 20 halibut for 14-day periods. This length of time was considered sufficient to reveal mortalities attributable to tagging type errors, the prime objective of the experiment. In addition, four groups were held for a 28-day period to reveal the presence of any possible delayed mortality. Subsequently one of these latter groups was retained for the duration of the 77-day experiment to observe the effects of prolonged retention.

All tagged fish between 80 and 119 centimeters were retained in the holding-box on the tagging vessel. Upon being tranferred to the live-boxes, no selection was made as to size or order of capture. Fish were placed in one live-box until 20 were impounded and then a second live-box would be filled. The specific fish placed in each live-box were not identified until the following day when their tag numbers were checked.

Transfer of the halibut from the holding-box to the live-boxes was accomplished by placing two or three fish in .006-inch thick polyethylene bags, 54-inches long by 26¾-inches in diameter, along with three to four gallons of water. The fish were then placed in an outboard skiff and taken to a position immediately over the live-boxes and handed to a diver in the water. The diver bled the air from the bag and swam with the fish directly into the live-box through the entrance tended by a second diver who prevented fish already confined from escaping. The fish were then pulled from the bag and released.

Normally, the fish did not struggle violently except briefly when transferred from the holding-box to the polyethylene bag. Upon being released into the live-box, their reactions varied greatly. Some appeared exhausted and remained motionless on the bottom. A few were extremely active and with a powerful burst of speed, would crash once or twice into the netting prior to quieting down. Generally however, most of the halibut were quiet in the time period immediately following placement into the live-boxes.

Every fish (identifiable by its tag number) was examined daily by divers within the live-box for any signs of distress or abnormal condition. The observations were recorded underwater on a slate. While one diver within the live-box was observing the fish a second diver checked the condition of the live-box.

On occasion the fish were observed to break through the nylon netting requiring daily repair of numerous small to occasionally large holes. Normally the smaller breaks were repaired before they became large enough to permit the passage of a fish. Unfortunately, 25 fish were lost during a four-day period when diving was suspended due to failure of the diving equipment. With this single exception, only two other fish escaped during the course of the experiments.

Certain behaviour patterns of the fish were observed during the course of the experiment. As mentioned earlier, immediately after being placed in the live-boxes, the fish were generally quiescent, probably reflecting the effects of the exertion, shock and physical injuries sustained during capture and transport from the fishing grounds. By the following day, these after-effects apparently terminated and the reactions of the halibut returned to "normal". When a diver entered the live-box, most of the fish would lie quietly while approached. But once approached within five or six feet, they would move away with a tremendous burst of speed, crashing into the netting of the live-box. This violent reaction subsided with subsequent encounters with a diver, and by the the third or fourth contact most of the fish would allow a very close examination for short periods of time. When they did move, they left slowly and usually avoided hitting the netting.

Within a few days after being placed in the live-boxes, the fish started burying themselves in the sand. This activity was generally restricted to the area immediately adjacent to the edges of the live-box. This burying presented minor problems as it created large openings under the lower edge of the pipe frame of the live-box which had to be filled daily. However, no fish escaped through these excavations during the experiments.

At the time of release from the live-boxes, each fish was examined for any obvious injuries resulting from retention and, if possible, the original hook wound was also re-examined. Their general condition and the alacrity with which they left the point of release was noted. If a fish was in obvious distress, it was not released but was retained for further observation. This occurred occasionally during the later stages of the experiment and in all cases the fish that were retained died within a period of three days.

One hundred eighty fish were released from the live-boxes during the course of the experiments of which 40 or just over 22% were recovered by 1964 by the commercial fisheries operating in northern British Columbia and southeastern Alaska waters. An additional 7 recoveries were reported from among the 27 fish that escaped, a return of the same magnitude. The pattern of recoveries was similar to the one observed in normal tagging experiments within the same general area, although the overall recovery rate was about 5 percent lower. This was not unexpected however as some of the fish, particularly those placed in the live-boxes after June 20, appeared to be in poor condition at the time of release resulting from factors which are discussed in the following section of this report.

SOURCES OF ERROR

Before discussing the results of this program, two major difficulties must be considered that became apparent during the course of the experiment. The first of

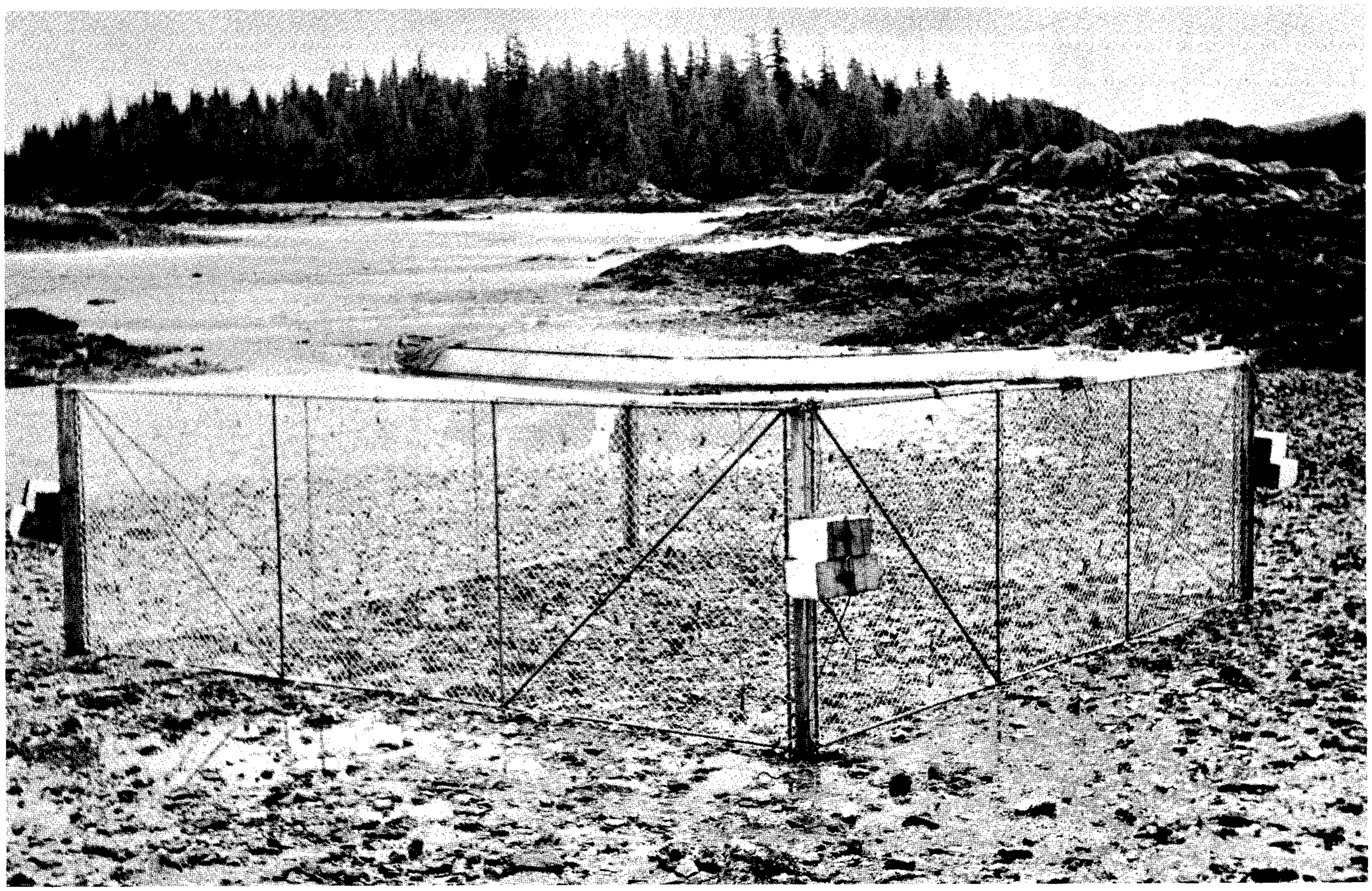

Figure 1. One of five identical live-boxes used in the 1960 viability experiments. The small floats on each corner and the large float on top of the live-box are attached temporarily to permit floating into position.

these was a significant deterioration in the physical environment occurring during the experimental period, particularly in the later stages.

The bottom temperatures found at the depths normally frequented by halibut range from 3° to 9° centigrade (Thompson and Van Cleve, 1936). Temperatures at Butler Cove greatly exceeded this range particularly during the latter half of the experiment. This is evident by examining the daily surface temperatures at Triple Island Lighthouse located 13 miles to the northwest at the entrance of Brown Passage, which is considered typical of the area in question (Hollister, 1961). Seven-day moving averages of these values are shown in Figure 2 along with the 9°C. baseline normally considered the upper limit for halibut. It is apparent that except for the month of May, the temperature conditions in Butler Cove were not desirable, particularly from the latter part of June through August.

Also shown in Figure 2 are surface salinities observed at Triple Island Lighthouse. The substantial decrease observed by late June is also a marked deviation from what would be normally encountered in waters frequented by halibut. The combined effect of decreasing salinities occurring simultaneously with increasing temperatures could only intensify the deterioration of the environment in the holding area with respect to halibut. These environmental changes undoubtedly had a profoundly adverse effect. There were only two deaths out of 100 fish placed in the live-boxes prior to the end of May, as compared to 22 deaths out of 37 fish placed in the live-boxes on July 20 and 21.

One of the severest conditions encountered by the fish was their removal from a cool natural bottom environment followed immediately by confinement in a much

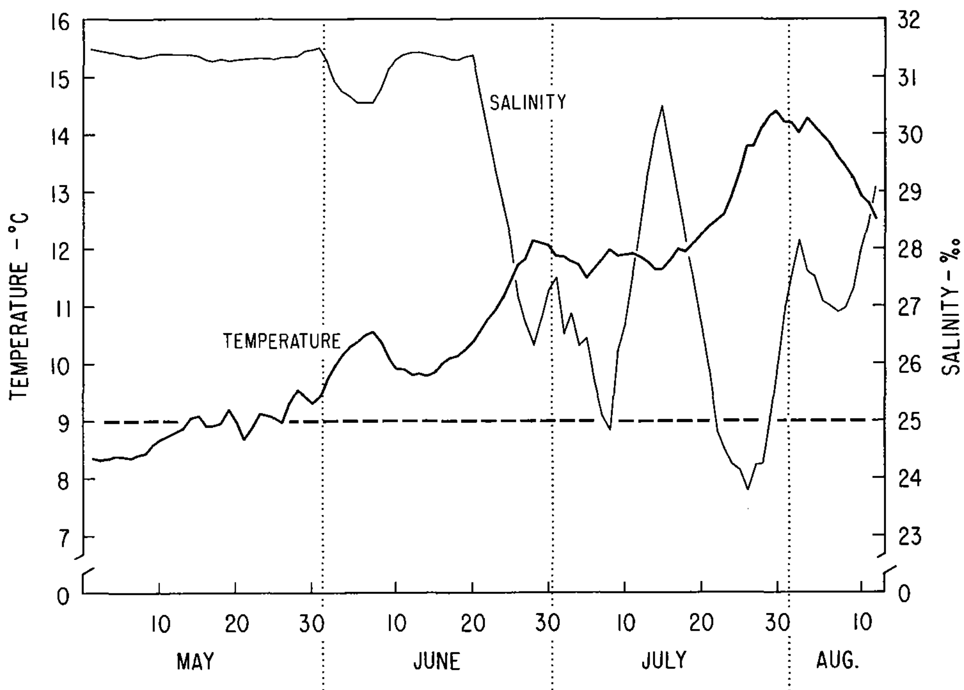

Figure 2. Seven-day moving average surface water temperatures and salinities recorded at Triple Island Lighthouse and a 9° Centigrade base line corresponding to the upper temperature limit at which halibut are normally found.

warmer surface environment. No method for acclimatization was feasible with the result that transfer into the holding-box must have placed a great deal of stress on the fish which had already sustained hook injuries and considerable unnatural treatment during the capture and tagging operations.

The benefits of a period of acclimatization are observable even within the experiment. Those fish that had been retained for three or more weeks, probably became adjusted to their environment before experiencing the highest temperatures occurring near the end of the experimental period and showed negligible mortality in comparison to fish placed in the live-boxes in mid-July.

A second problem arose when unexpected difficulty in obtaining adequate numbers of fish for the experiment and the desirability of providing predetermined numbers resulted in a tendency to use fish that normally would have been rejected for tagging. The latter is evident in Table 2 which compares the incidence of various classes of hook injuries in fish delivered to Butler Cove with all other fish tagged in northern Hecate Strait and Dixon Entrance during the same time period.

Injuries are classified into four general types. Hook injuries on the left side of the head, either in the jaw or in the cheek area, are the most common type of injury observed in setline-caught halibut and the least serious for tagging purposes. As there are no vital organs in this area on the head, the majority of the halibut in most tagging experiment tend to consist of fish with this type of wound.

Fish hooked on the right side of the head occur less frequently and usually appear to be more seriously injured, primarily because of wounds in or near the eyes. Thus fewer are judged taggable, and only a small percentage of the fish in any tagging experiment have injuries in this part of the head.

A small number of fish are caught with a variety of relatively minor injuries that are grouped in a miscellaneous category.

The most serious category of hook injury includes wounds in the roof of the mouth region and in the musculature of the pharyngeal pads. The close proximity of the hook to the brain and the soft easily-torn tissues in this area necessitate great care in evaluating the suitability of such fish for tagging. While this type of hook wound occurs frequently, normally only the larger fish with such an injury are taggable because the hook tends to damage too large a proportion of tissue in the smaller sizes.

In these experiments however, this type of injury occurred over twice as often as expected under normal tagging conditions ($x^2 = 37.311$, 3 d.f.). This tendency to tag fish injured more severely than usual, in addition to expecting them to recover in a substandard environment, undoubtedly was responsible for much of the ultimate mortality encountered in the experiment.

Table 2. Chi-square Test for Difference in Incidence of Various Hook Injuries Between a Normal Tagging Operation in the Northern Hecate Strait - Dixon Entrance Area, and the Fish Used in the Viability Experiments.

Injury	Normal Tagging Observed	Normal Tagging Percent	Butler Cove Tagging Observed	Butler Cove Tagging Expected	Chi-Square
Left Jaw-cheek	803	74.35	175	194.1	1.879
Right Jaw-cheek-eye	98	9.08	19	23.7	.932
Roof-of-mouth	113	10.46	57	27.3	32.311
Miscellaneous	66	6.11	10	15.9	2.189
TOTAL	1080		261	261.0	37.311

The experiment commenced on May 13 with the delivery of the first 20 halibut and ended on August 4, with the release of the survivors of the last two groups held. Figure 3 shows a chronology of 261 fish that were under confinement during the experimental period, including numbers of fish placed in the live-boxes, the number of mortalities and the incidence of escapes.

Fish used in the experiments were restricted chiefly to individuals with a total length of between 80-119 centimeters inclusive. Only nine between 75-79 centimeters were included. This size range was chosen to include fish that were completely recruited into the setline fishery while avoiding the problems of working with fish over 50 pounds live weight. Also results obtained from this size class would be most useful in evaluating past tagging experiments as fish between 80-119 centimeters are the dominant size previously tagged in Area 2. A chi-square test utilizing all data except for the fish that escaped (Table 3) showed no differential mortality within the range of sizes utilized. ($x^2 = 7.388$, 5 d.f.).

Table 3. Chi-square Test for Difference in Number of Mortalities by Size.

Size Categories	Observed Dead	Observed Alive	Total	Expected Dead	Expected Alive	Chi-square
75-79	3	6	9	2.1	6.9	1.046
80-84	12	61	73	16.8	56.2	
85-89	11	38	49	11.3	37.7	.010
90-94	8	25	33	7.6	25.4	.027
95-99	3	21	24	5.5	18.5	1.474
100-104	6	9	15	3.4	11.6	2.273
105-109	3	8	11	2.4	8.6	
110-114	5	7	12	2.8	9.2	2.558
115-119	3	6	9	2.1	6.9	
TOTAL	54	181	235	54.0	181.0	7.388

It was also desirable to determine if a differential mortality might occur between sexes. Inasmuch as the sex of halibut can only be determined by direct examination of the gonads, the expected ratio of males to females was based on the total sexed dead fish sample available from the tagging vessel from fishing done in areas and time periods when fish were obtained for the viability experiments. The expected ratio for fish between 75-119 centimeters in length indicated 40.4 males to 59.6 females. Assuming this relationship should also hold for the experimental fish a chi-square test (Table 4) was not significant ($x^2 = 1.369$, 1 d.f.).

Table 4. Chi-square Test for Difference in Mortality by Sex.

Sex	Observed	Expected	Adjusted Chi-square
Male	16	20.6	.816
Female	35	30.4	.553
TOTAL	51*	51.0	1.369

* Sex not determined for three mortalities.

CAUSES OF MORTALITY

A thorough examination was made of each mortality. Each fish was carefully dissected and examined as to the possible cause of death whether by a related tagging injury or other natural cause. The hook injury itself was examined for evidence of

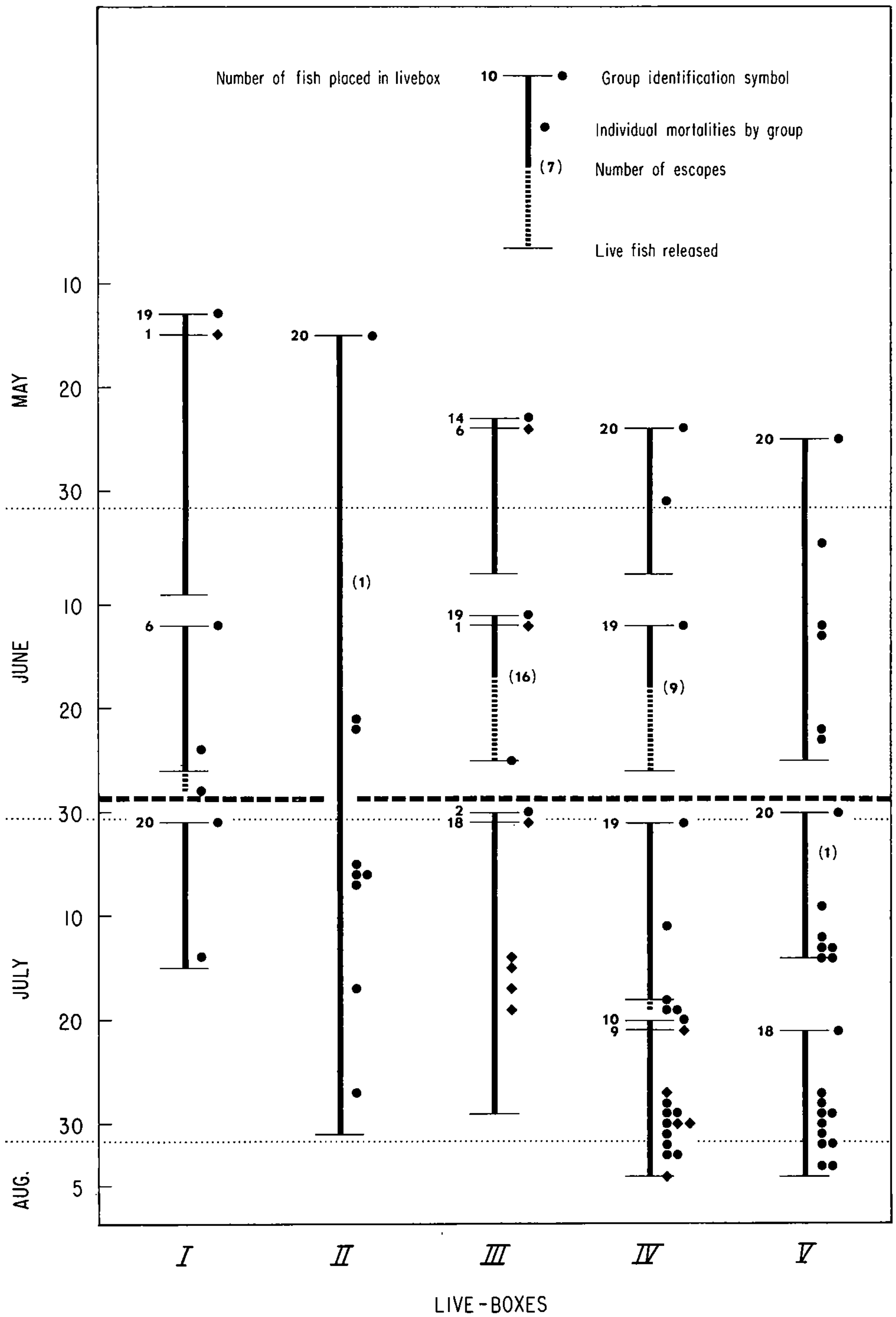

Figure 3. Chronological summary of holding experiments showing numbers of halibut placed in live-boxes; number of escapes; and number of mortalities.

healing or of degeneration and possible infection. In many cases, the seriousness of an injury was difficult to evaluate as the injured tissues deteriorated rapidly following death, even within the maximum of 24 hours that a fish could remain undetected between daily observations of the live-boxes. The major changes in environmental conditions occurring throughout the duration of the experiment further complicated any evaluation as to the probable causes of mortality. Not only did it become increasingly difficult for the fish to recover from their injuries with the rising temperatures, those that died evidenced an increasingly rapid deterioration of the scar tissues surrounding the hook wound.

For the purposes of analysis, the experiment has been divided into groups by time periods. Period A will include all fish present in the live-boxes prior to June 29, and Period B will include those present subsequent to that date. This division takes into account the changes occurring in the environment, with all of Period A except for possibly the last week providing fairly reasonable environmental conditions for halibut whereas all of Period B encompassed a non-typical and aberrant environment (see Figure 2). Time period B is further subdivided into groups B-1 and B-2, with group B-1 consisting of fish placed in the live-boxes on June 30 and July 1, and group B-2 consisting of fish placed in the live-boxes on July 20 and 21. The basic data for all mortalities occurring throughout the experiment are listed in the Appendix Tables by these divisions (mortalities for fish in livebox II which were held for the duration of the experiment are listed separately).

In Period A of the experiment (including live-box II up to four weeks of retention) the causes of death are reasonably definable for the 9 that died out of the 120 fish involved. The first two deaths which occurred in live-boxes IV and V on May 31 and June 4, the 7th and 10th day of retention respectively, were both a result of undetected hook injuries. The next two mortalities which occurred in live-box V on June 12 and 13 have been classified as probable natural deaths as both fish showed positive evidence of apparent "natural" maladies, whereas the hook injuries showed definite signs of healing and there were no secondary injuries that could be attributable to tagging.

Between the 22nd and the 26th of June when all fish in the live-boxes were released, four additional mortalities occurred, one each on the 12th and 16th day of retention in live-boxes I and III respectively and one each on the 28th and 29th days of retention in live-box V. All of the deaths were of a similar nature, apparently resulting from a failure to recover from hook injuries and showing serious deterioration of the associated wounds. It should be noted that three of these fish which had serious roof-of-mouth injuries probably would not have been tagged in a normal tagging operation. The fourth death apparently resulted from the failure of a torn left-cheek injury to heal properly. It is surmised that none of these fish had recovered from injuries received at the time of tagging, and thus have been classed as deaths due to the tagging process.

A fifth mortality from live-box I on June 28 has been judged as having been caused by conditions related to the experiment rather than the actual tagging procedure (see Appendix Table I).

It should be noted that all five of these latter deaths occurred during the period associated with the commencement of a rapid rise in temperature and a rapid decrease in salinity. These conditions may well have been partially responsible for the marked increase in mortalities observed at this time. It is noteworthy that prior to this time none of the dead fish exhibited any tendency towards deterioration of the tissues surrounding the hook injury.

Mortalities occurring in Period B after June 29 become extremely difficult to evaluate as to probable cause of death. Out of 78 fish in group B-1 (excluding 1 escape) and 37 fish in group B-2, 15 and 22 fish died respectively. In referring to the apparent causes of death for group B-1 as listed in Appendix Table II, it will be noted that the majority of deaths appear to be the result of failure to recover from the hook injuries received at the time of tagging. One fish hooked in the pericardial cavity and a second fish inadvertently gaffed in the top of the head would probably have died under any conditions. A third death is listed as cause unknown. The remaining 12 deaths however, all appeared to be a direct result of, or associated with failure to recover from tagging injuries.

Reference to the apparent causes of death for group B-2 in Appendix Table III will reveal that three fish had sustained injuries serious enough that they may have been expected to die under good environmental conditions. Two of these fish were hooked in the gullet and the third had sustained a broken back during some stage of the tagging operation or holding experiments. A fourth death may have been from natural causes. Of the remaining 18 mortalities, 10 are listed as hook injuries that had not healed and eight are listed as deaths for which no cause was apparent. The notable increase in failure to recover from tagging injuries practically nullified the value of any information obtained from this portion of the experiment.

The overall mortality, irrespective of cause, was 7.5 percent for fish held in the live-boxes during Period A. In group B-1 the overall mortality had increased to 19.2 percent, an increase of over 2.5 times. In group B-2 the mortality increased to 59.5 percent, over three times that observed in group B-1 and eight times that observed in Period A. It would seem improbable that increases in mortality of the magnitude observed between Period A and group B-1 and between groups B-1 and B-2 could occur unless the fish had sustained some type of differential treatment. All fish were handled essentially the same however, with the one difference being a marked deterioration in the environment during the latter part of the experiment. Thus, it must be assumed that this change was in fact largely responsible for the failure of the fish to recover from the injuries received at tagging.

OBSERVATIONS DURING PROLONGED RETENTION

Prior to the start of the experiment, it was decided to hold one group of fish for the duration of the experiment to determine the length of time required for complete recovery from the injuries received at the time of tagging and to observe what effects prolonged retention might have upon halibut. Thus 20 halibut captured on May 15 were placed in live-box II and retained until July 31, a total of 77 days of confinement. One additional fish tagged on May 25 was transferred to live-box II from live-box V on June 26, and also retained until July 31, a total period of 67 days.

All fish were in excellent condition during the first month of retention, with no mortalities and no sign of weakness or disability. One fish escaped on the 24th day, the only loss of this type occurring during the entire two and one-half month holding period.

By the middle of June a noticeable slowing down in the activity of the fish was observable, with most of the fish appearing weaker. Shortly thereafter, on June 21 and 22, the 37th and 38th days of retention, the first two mortalities occurred. As the tagging injuries were definitely healing and there were no obvious causes for mortality in either fish it was concluded that death was most probably either a result of some aspect of confinement or actual natural mortalities.

While no additional mortalities occurred for the next two weeks, the fish continued to show signs of reduced activity within the live-box. They were very easy to approach and made little or no effort to avoid contact and handling by the divers, although this may have been due in part to conditioning to the diver's daily visit.

During the three-day period, from July 5 to 7 inclusive, a series of four deaths occurred, none of which presented any evidence of being caused directly or indirectly by the tagging process. In each case, there were definite signs that the hook injuries were healing. In all four fish, the stomach and intestinal tract were quite shrunken, clearly showing the effects of seven weeks without food. It seems possible that unknown effects of confinement and lack of food, aggravated by the unusual environment had created conditions that might not become critical under a normal situation.

Two separate attempts at feeding were made in late May and mid-June, but in both cases the fish refused to eat even though food was left in the live-boxes for extended periods of time. However, on July 15 when food consisting of herring, chunks of sablefish and octopus was again presented to the fish almost all took food readily. However, fish confined in other live-boxes for shorter periods of time would not eat. Food was available for three days during which time most fish continued to feed. The effect upon the fish was pronounced. Almost without exception they became livelier. Their movements within the live-box increased and they were more difficult to approach, moving away rather than remaining stationary on the bottom as had been the case prior to feeding. This rejuvenation undoubtedly benefitted those that survived and that were ultimately released.

Two additional mortalities occurred before the fish in live-box II were eventually released, one on the 63rd and one on the 73rd day of confinement. In both cases the hook injuries appeared fully healed, and neither appeared to have died as a result of injuries received at tagging. This observation gives some indication as to the length of time it might take halibut to fully recover from the effects of tagging. This time period might be reduced under better environmental conditions for injuries of comparable seriousness (both fish had sustained left-jaw hook injuries), whereas a more severe injury might require a longer recovery period. Interestingly two and one-half months is approximately the same time lag observed between tagging and the first substantial 0-year recoveries of tagged halibut in the commercial setline fishery (Myhre, 1967), suggesting that this lag in returns may be associated with the time required to recover from injuries or trauma incurred at tagging. A cessation of feeding might also be implied by the refusal of the halibut to take food during two attempts at feeding made during May and June, although it is often observed that animals, including fish, placed in captivity require a period of adjustment before accepting food. The 12 fish released on July 31 appeared to be in good condition considering the long period of confinement under adverse conditions.

MORTALITY ESTIMATES

The maximum possible mortality, regardless of cause of death or time period in which the deaths occurred, is 19.6 percent or 46 out of 235 useable fish (excluding deaths occurring in live-box II after one month of retention). Because of factors already discussed, data from June 29 to the end of the experiment cannot be considered typical of the actual viability of halibut found in their natural environment and will not be considered further except to note that 37 out of 115 or 32.2 percent of the fish held during this period died. Thus, 80.4 percent of the total mortality occurred in less than half of all fish retained.

Limiting consideration to the 120 fish retained prior to June 30, a total of nine or 7.5 percent died. This value includes all mortalities regardless of the apparent cause of death. Of this number, three can be excluded as resulting directly from any part of the tagging operation, two probably dying of natural causes (possibly aggravated by tagging and confinement) and one dying as a result of poor experimental procedure, thus giving an estimate of mortality attributable to tagging (Type A error) at 5.0 percent. If consideration is restricted to mortalities occurring during the first 14 days of retention, only four deaths are attributable to tagging. Further restricting this estimate to only those fish placed in live-boxes during May when the environment was most typical of that in which halibut might be found, only two out of 100 died, both obvious tagging deaths. To summarize, the best estimate as to the number of deaths arising as a direct result of tagging in these experiments probably lies between a minimum of 2.0 percent to a maximum of 5.0 percent.

Considering all fish held 14 days a total of 36 out of 261 died. Assuming that there were no mortalities among 26 fish that escaped during the 14 days, the instantaneous mortality rate for the first two weeks following tagging is equal to .158. This value, even though it includes deaths during the entire course of the experiments and deaths not attributable to tagging, is substantially less than a value of .690 calculated from the 1958 experiments. Restricting useable observations to that portion of the experiment conducted prior to June 29, before the environment became unsuitable with respect to halibut, a total of four out of 120 fish died and 25 escaped which is an instantaneous mortality of .038.

DISCUSSION

This type of experiment is subject to several limitations. Confining halibut, even under the most ideal circumstances may reduce their viability and particularly so under the conditions encountered during the later phase of the 1960 experiments. In addition the need to relax the criteria normally used for selecting fish suitable for tagging in order to provide sufficient numbers of experimental fish along with the additional handling involved in the study would also reduce viability. These considerations would lead to an overestimation of the mortality rate.

Conversely, mortality rates may be underestimated where confinement may have protected the fish during a critical period, or if there is in fact a substantial delayed mortality occurring after the experimental holding period. Recoveries by the commercial fishery of the tagged fish released from the live-boxes did not suggest mortalities of this type.

SUMMARY

Experiments were conducted in 1958 and 1960 respectively in which tagged setline-caught Pacific halibut were maintained in captivity for the purpose of evaluating the magnitude of possible mortality resulting from the capture and tagging operations (Type A error of Ricker).

Floating live-boxes of wire-mesh construction used in 1958, proved to be unsatisfactory for holding halibut.

Underwater live-boxes using nylon netting over a pipe framework were used in 1960 and proved to be adequate for maintaining halibut in captivity for extended periods of time.

Fish held for 2½ months refused food prior to the end of the second month. This corresponded to the time period in which complete healing of the hook injuries was observed to have occurred. These observations are in general agreement with the observed lag in the 0-year recoveries of tagged halibut in a normal tagging experiment.

Under live-box conditions approximating their natural environment the fish were observed to recover quickly from the effects of tagging and handling. Observations made within 12 hours of placement in the live-boxes revealed no obvious loss of reaction time.

No mortalities occurred prior to the sixth day of retention. Thus hyperactivity, which has been observed as a major cause of mortality for other species of line-caught fish appears to be negligible in setline-caught halibut.

A best estimate of instantaneous tagging mortality of .038 has been determined for the basic 14-day holding period used in this study. In view of the rigorous treatment and adverse conditions to which the fish were subjected, this estimate is probably close to the maximum that would be expected in a normal halibut tagging operation.

APPENDIX

Table I. Tagging and Mortality Data for Fish that Died While Under Confinement: Period A.

Tag Number	Tagging Length	Sex	Date of Tagging	Date of Death	Days in Live-box	Tagging Injury*	** Apparent Cause of Death
Live-box I							
240	89	M	6/12	6/24	12	LC torn	Injury serious. Most of cheek eroded away.
256	81	M	6/12	6/28	16	LJ torn	No apparent cause.***
Live-box III							
219	86	F	6/11	6/25	14	RM	Injury extremely serious, palate completely torn. Cranial bones exposed.
Live-box IV							
185	105	F	5/24	5/31	7	LC	Hooked in gullet.
Live-box V							
196	80	—	5/25	6/4	10	Tongue	Second and third gill arches severed.
198	80	M	5/25	6/12	18	LC	Anterior segments of liver badly infected. Hook injury healing.
187	80	F	5/25	6/13	19	Lower jaw	Complete degeneration of kidney tissue. Hook injury healing.
206	94	—	5/25	6/22	28	RM	Injury not healing. Cranial bones exposed.
202	81	F	5/25	6/23	29	RM	Injury not healing. Cranial bones exposed.

* Abbreviations used are as follows: LC — Left cheek, LJ — Left jaw, RM — Roof-of-mouth, RC — Right cheek.

** Injury in all cases refers to the tagging injury listed in the preceding column.

*** This fish was subjected to unusual handling procedures. It was retained in the plastic bag used during transfer to the live-box in excess of ten minutes, while in a deficient amount of water. It was noticeably bleeding when placed in the live-box. As this fish was in obvious distress, it was retained beyond the normal release date.

Table II. Tagging and Mortality Data for Fish that Died While Under Confinement: Group B-1.

Tag Number	Tagging Length	Sex	Date of Tagging	Date of Death	Days in Live-box	Tagging Injury*	Apparent Cause of Death
Live-box I							
332	87	F	7/1	7/14	13	LJ	Gaffed in head, wound entering cranial area.
Live-box III							
302	82	M	7/1	7/14	13	RM	Injury serious.
296	86	M	7/1	7/15	14	RM	Injury serious. Body cavity filled with water, cause unknown.
301	100	F	7/1	7/17	16	RM-RJ	Injury not serious but apparently infected.
289	93	F	7/1	7/19	18	RM	Injury extremely serious.
Live-box IV							
340	91	F	7/1	7/11	10	RM	Injury extremely serious.
316	89	F	7/1	7/18	17	LJ	Body cavity filled with water, cause unknown. Injury fairly serious.
338	114	F	7/1	7/19	18	RM	Injury serious.
347	84	M	7/1	7/19	18	RM	Injury serious. Body cavity filled with water, cause unknown.
Live-box V							
266	103	M	6/30	7/9	9	LJ	Hooked in pericardial cavity.
269	83	F	6/30	7/12	12	LJ	No apparent cause. Injury not serious.
274	108	F	6/30	7/13	13	LJ	No apparent cause. Injury not serious. Slight excess of fluid in body cavity.
288	101	F	6/30	7/13	13	LJ	Injury serious, extending to left-cheek area.
277	97	F	6/30	7/14	14	LJ	Injury serious, extending to left-cheek area.
282	91	F	6/30	7/14	14	LJ	Injury serious, apparently infected.

Table III. Tagging and Mortality Data for Fish that Died While Under Confinement: Group B-2.

Tag Number	Tagging Length	Sex	Date of Tagging	Date of Death	Days in Live-box	Tagging Injury*	Apparent Cause of Death
Live-box IV							
367	87	M	7/21	7/27	6	LJ	Hooked in gullet.
352	110	F	7/20	7/28	8	LJ	Broken spinal column, vertebrae separated, cause unknown.
350	91	M	7/20	7/29	9	LJ	No apparent cause. Injury in fair condition.
356	82	F	7/20	7/29	9	LJ	No apparent cause. Injury not serious.
351	88	F	7/20	7/30	10	LJ	No apparent cause. Injury not serious.
373	80	F	7/21	7/30	9	RM-LC	Injury fairly serious.
377	80	F	7/21	7/30	9	LJ	Injury not healing properly.
361	75	M	7/20	7/31	11	LJ	Injury extending into roof-of-mouth area and quite serious.
355	85	F	7/20	8/1	12	LJ	No apparent cause. Injury not serious.
359	96	M	7/20	8/2	13	LJ	Injury fairly serious, extending close to cranial bones.
362	75	F	7/20	8/2	13	LJ	No apparent cause. Fish in excellent condition.
379	87	F	7/21	8/4	14	LJ torn	No apparent cause. Injury not serious.
Live-box V							
366	103	F	7/21	7/27	6	RM	Injury extremely serious.
376	93	M	7/21	7/28	7	RM-LJ	Injury serious.
384	104	F	7/21	7/29	8	LJ torn	Injury fairly serious.
389	89	F	7/21	7/29	8	LJ torn	Hooked in gullet.
369	77	M	7/21	7/30	9	RM	Injury extremely serious.
396	101	F	7/21	7/31	10	LJ	Injury serious in cheek area.
375	108	F	7/21	8/1	11	LJ	Injury extending into palate area, fairly serious.
378	119	M	7/21	8/1	11	LJ	No apparent cause. Injury not serious. Some loss of skin and scales on ventral side of abdomen.
363	91	F	7/21	8/3	13	LJ	No apparent cause. Injury moderately serious.
372	110	F	7/21	8/3	13	LJ	Ruptured liver. Injury not serious.

Table IV. Tagging and Mortality Data for Fish that Died While Under Confinement: Live-box II.

Tag Number	Tagging Length	Sex	Date of Tagging	Date of Death	Days in Live-box	Tagging Injury*	Apparent Cause of Death
Live-Box II							
132	119	F	5/15	6/21	37	LJ	No apparent cause. Injury not serious.
139	117	—	5/15	6/22	38	LJ	No apparent cause. Injury starting to heal.
125	83	M	5/15	7/5	51	LJ	No apparent cause.
130	113	F	5/15	7/6	52	LJ-LC torn	Intense infammation and swelling about left eye, cause not apparent. Injury healing.
141	93	F	5/15	7/6	52	RC	Liver apparently diseased. Injury healing.
137	98	F	5/15	7/7	53	LJ	No apparent cause.
129	85	M	5/15	7/17	63	LJ	No apparent cause.
131	111	F	5/15	7/27	73	LJ	Ovaries degenerated to greyish, watery fluid. Injury healed.