NOTES

INCORPORATING SOAK TIME INTO MEASUREMENT OF FISHING EFFORT IN TRAP FISHERIES

While it is recognized that soak time (number of days a trap is allowed to fish before it is retrieved) is an important fishing strategy decision for the individual fisherman, there is surprisingly scarce information on the subject. Little data is available on the relationship between catch and soak time. Similarly, the implications of variable soak times have not been widely discussed.

This paper develops a model to determine the profit-maximizing soak time for an individual fisherman in the Florida spiny lobster, *Panulirus argus*, fishery. This establishes the relative importance of soak time as one of the components of fishing effort in trap fisheries and leads to suggestions for incorporating soak time into the traditional measurement of trap days to more accurately reflect fishing effort in trap fisheries.

Profit-Maximizing Soak Time

Catch per trap day was regressed on soak time with the data collected by Robinson and Dimitriou (1963). The best statistical fit using ordinary least squares is in the form of Equation (1) (Figure 1).

$$\frac{C}{D} = \frac{\alpha}{S^{\beta}} \tag{1}$$

where C = catch per trap haul
D = days fished for the sample
S = soak time in days
$\alpha = 2.94$, $\hat{t}_{\alpha} = 5.40$
$\beta = 0.90$, $\hat{t}_{\beta} = 11.25$
year: 1963
$n = 25$
$R^2 = 0.86$.

Since the number of days fished (D) in this field experiment was synonymous with the soak time ($D = S$), then:

$$C = \alpha S^{(1-\beta)}. \tag{2}$$

Taking the first and second derivatives of Equation (2) with respect to the soak time:

$$\frac{dC}{dS} = \frac{(1-\beta)\,\alpha}{S^{\beta}} > 0 \tag{3}$$

$$\frac{d^2C}{dS^2} = \frac{(\beta^2-\beta)\,\alpha}{S^{(1+\beta)}} < 0. \tag{4}$$

Equations (3) and (4) imply the catch per trap haul increases at a decreasing rate with respect to the soak time (Figure 2). This relationship seems

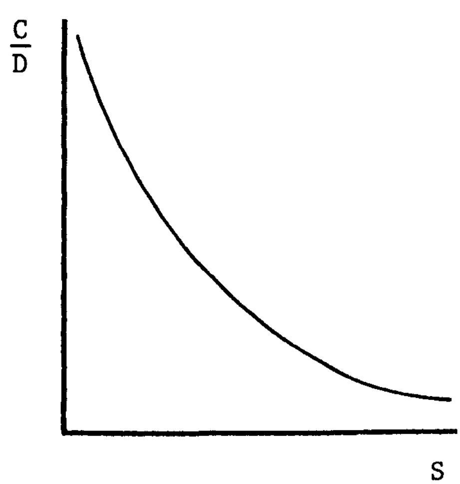

FIGURE 1.—Catch per day with respect to the soak time.

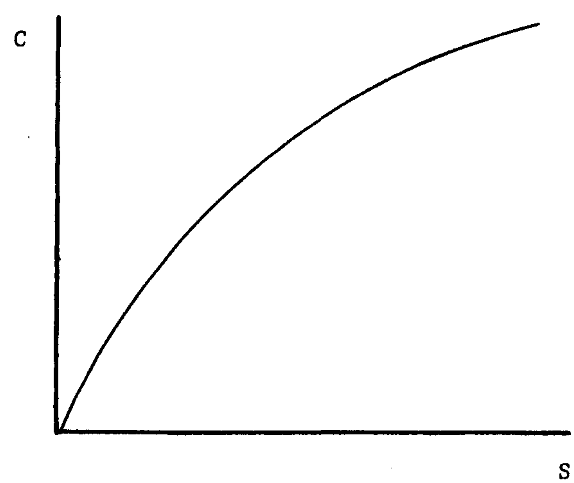

FIGURE 2.—Catch per haul with respect to the soak time.

reasonable for traps that attract fish because they are baited, or because the trap acts as a refuge, or some combination of both reasons. This relationship has been observed by Thomas (1973) in the Maine (American lobster, *Homarus americanus*) fishery and by Warner (pers. commun.) and Simmons (pers. commun.) for Florida Keys and Bahama spiny lobster trap fishing. The distinction would be that the catch curve for traps that are highly dependent on baiting would presumably be relatively steeper than for less bait-dependent traps reflecting the relative attracting power of the bait during the initial soak time.

In both cases it is expected that the total catch per trap haul would peak and perhaps even decrease with very long soak times either because of mortality in the trap (starvation, cannibalism, predation) or escapement. Therefore, while it is recognized that the catch per trap haul with respect to the soak time is probably sigmoidal shaped, the negatively sloped portion that would be associated with long soak times is excluded from the model on the assumption it is not within the range of normal commercial fishing strategies.

The number of times each trap is hauled in a given time period (e.g., 1 mo) is the number of days in the time period divided by the soak time (in days). The total catch for the given fishing period would be the catch per trap haul Equation (2) times the number of times each trap is hauled (D/S) times the number of traps (T).

$$L = \left[\alpha S^{(1-\beta)}\right]\left(\frac{D}{S}\right)(T) = \frac{\alpha DT}{S^{\beta}} \tag{5}$$

where L = total catch in the fishing period
T = number of traps fished
D = number of days in the fishing period
S = soak time in days.

Taking the first and second derivatives of Equation (5) with respect to the soak time:

$$\frac{\partial L}{\partial S} = \frac{-\beta\alpha DT}{S^{(1+\beta)}} < 0 \tag{6}$$

$$\frac{\partial^2 L}{\partial S^2} = \frac{(\beta + \beta^2)\,\alpha DT}{S^{(2+\beta)}} > 0. \tag{7}$$

Equations (6) and (7) imply that, holding the number of traps constant, the total catch for the fishing period decreases at a decreasing rate with respect to the soak time (Figure 3). This is because a longer soak time increases the catch per trap haul but decreases the number of hauls possible in the fishing period.

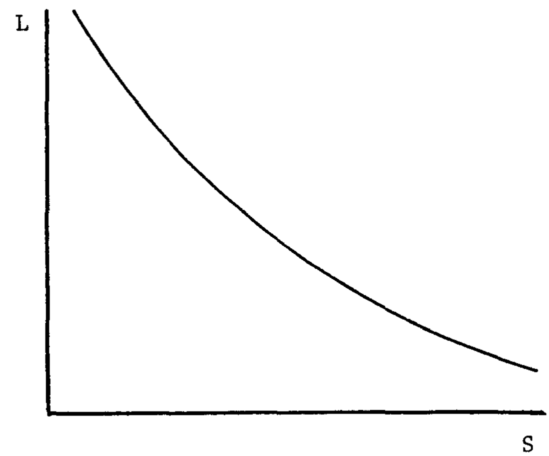

FIGURE 3.—Total catch in the fishing period with respect to the soak time.

Holding the number of traps constant is a highly restrictive condition. The advantage of increasing the soak time would be to permit the individual fisherman to operate more traps. The most reasonable constraint measurement for fishing capabilities is a maximum number of hauls in a fishing period.

It is assumed an individual vessel can make a constant (maximum) number of hauls during the fishing period. This maximum is predicated on characteristics of the vessel, number in the crew, distance traps are set from port, depth of water, and weather conditions.

$$H \equiv \left(\frac{D}{S}\right)T \tag{8}$$

$$H = K \tag{9}$$

where H = total number of trap hauls in D days
K = maximum number of trap hauls in D days.

Substituting Equation (9) into Equation (8) and rearranging:

$$T = \frac{SK}{D} \tag{10}$$

Substituting Equation (10) into Equation (5) results in a total catch equation where both the soak time and number of traps vary in combinations that always result in the maximum number of possible hauls.

$$L = \left(\frac{\alpha D}{S^{\beta}}\right)\left(\frac{SK}{D}\right) = \alpha K S^{(1-\beta)}. \tag{11}$$

Taking the first and second derivatives of Equation (11) with respect to the soak time:

$$\frac{dL}{dS} = \frac{(1 - \beta)\,\alpha K}{S^{\beta}} > 0 \tag{12}$$

$$\frac{d^2L}{dS^2} = \frac{(\beta^2 - \beta)\,\alpha K}{S^{(1+\beta)}} < 0. \tag{13}$$

Equations (12) and (13) imply that, holding the number of total hauls constant, the total catch increases at a decreasing rate with respect to the soak time (Figure 4). This is because a longer soak time decreases the catch per trap day but increases the number of traps that can be fished.

The fisherman/entrepreneur is not interested in maximizing the catch per trap day, the catch per trap haul, or the total catch. He presumably wants to maximize the net economic return (profit) from fishing which is the difference between the total revenue and total cost of his fishing activities. The total revenue is equal to the ex-vessel price times the catch. In the case of an individual fisherman, it can normally be assumed that the price is constant over all catch ranges. This is because the catch of an individual fisherman is relatively small compared with total landings in the fishery and will, therefore, not have a significant influence on the prevailing ex-vessel prices.

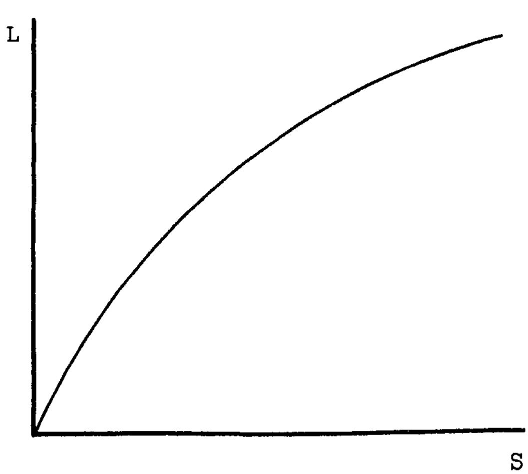

FIGURE 4.—Total catch in the fishing period with respect to the soak time, given combinations of soak time and number of traps that always result in the maximum number of hauls.

$$TR = \rho L \tag{14}$$

where TR = total revenue
ρ = ex-vessel fish price (per pound round weight).

Total fishing costs are comprised of fixed investment costs, trap hauling costs, and trap costs:

$$TC = I_K + H_K + \delta T \tag{15}$$

where TC = total fishing costs
I_K = fixed costs (e.g., vessel depreciation, insurance, routine maintenance) on equipment capable of K hauls in D days
H_K = costs of K hauls
δT = costs of traps
δ = unit cost (depreciated value and maintenance cost) of a trap for the fishing period (D days).

Trap hauling costs are treated as a constant in the model because the number of hauls is held constant. It is recognized that trap hauling costs are dependent on factors such as fishing depth and the distance traps are set from port as well as the number of trap hauls. This model assumes these factors are relatively constant. In the case of Florida spiny lobster fishing, this may not be too unreasonable an assumption because fishermen customarily fish the same area for considerable periods of time. When the assumption does not hold, neither does the assumption about a constant maximum number of hauls.

Since the model is an analysis of changes in soak time and traps fished, the constant costs in the model (I_K and H_K) play minor roles. It is assumed that with the profit-maximizing soak time and number of traps that total revenue will be greater than total costs. If total costs were greater than total revenue for all soak times and number of traps fished, then presumably fishermen would stop fishing to avoid incurring continuous losses. Profit (π) is defined as total revenue (Equation (14)) minus total costs (Equation (15)):

$$\pi = \rho L - I_K - H_K - \delta T. \tag{16}$$

Substituting Equations (10) and (11) into Equation (16):

$$\pi = \rho\left[\alpha K S^{(1-\beta)}\right] - I_K - H_K - \delta\left(\frac{SK}{D}\right). \quad (17)$$

Taking the first and second derivatives of Equation (17) with respect to the soak time:

$$\frac{d\pi}{dS} = \frac{(1-\beta)\,\rho\alpha K}{S^{\beta}} - \frac{\delta K}{D} \gtrless 0 \quad (18)$$

$$\frac{d^2\pi}{dS^2} = \frac{(\beta^2-\beta)\,\rho\alpha K}{S^{(1+\beta)}} < 0. \quad (19)$$

The profit-maximizing soak time can be determined by setting Equation (18) equal to zero and solving for S (Figure 5):

$$S_\pi = \left[\frac{(1-\beta)\,\rho\alpha D}{\delta}\right]^{\frac{1}{\beta}}. \quad (20)$$

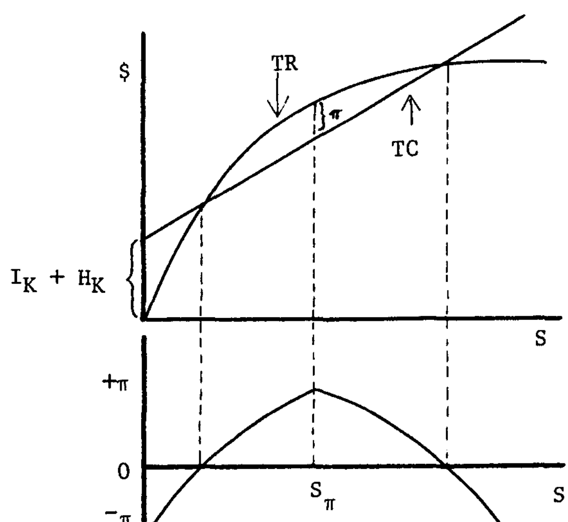

FIGURE 5.—Total revenue, total cost, and profit with respect to the soak time, given combinations of soak time and number of traps that always result in the maximum number of hauls.

The parameters prevailing in 1962 were:

Purchase price of a trap: \$6.00
Maintenance cost of a trap over its life span: (0.25)(cost) = \$1.50
Total cost of a trap: \$7.50
Estimated life span of a trap: 1.5 seasons or 12 mo
δ = depreciated value of a trap for D days use (1 mo)
$\delta = 63¢$
$\rho = 38.3¢$
$D = 30$
$\alpha = 2.94$
$\beta = 0.90$
$S_\pi = 6.52$ (as estimated by Equation (20)).

The theoretically profit-maximizing soak time compares favorably with the average soak time of 6-7 days in 1962 (October-December) observed by Robinson and Dimitriou in the commercial fishery. This favorable comparison should be interpreted with reservations. First, Equation (1) was estimated from a small sample (25 observations). Second, the model is sensitive to trap costs and the method of calculating these costs is rather crude. The life span of traps varies significantly. Furthermore, maintenance costs involve removing underwater growth (traps fish better when they are clean) and onshore storage costs that vary considerably at different locations.

Influence of Relative Abundance on Soak Time and Catch per Trap Day

The catch per trap day may not reflect declining relative abundance (decreasing α in the model). As the exploitable stock declines so will the profit-maximizing soak time (Equation (20)). This reduces the number of traps each vessel can operate (given a maximum number of hauls) but increases the catch per trap day relative to what would have prevailed with the originally longer soak time. The net result is that as α declines the catch per trap day will remain constant. This can be seen by substituting Equation (20) into Equation (1).

$$\frac{L}{TD} = \frac{\alpha}{S_\pi^{\beta}} = \frac{\alpha}{\left[\left[\frac{(1-\beta)\,\rho\alpha D}{\delta}\right]^{\frac{1}{\beta}}\right]^{\beta}}$$

$$= \frac{\delta}{(1-\beta)\,\rho D}. \quad (21)$$

Equation (21) and Table 1 indicate that the measured catch per trap day will not vary with changes in the exploitable stock when the soak time also adjusts to the exploitable stock.

TABLE 1.—Catch per trap day that would be recorded with a declining stock (decreasing α) with constant (column 6) and variable (column 8) soak times.

α	β	ρ	δ	S	$L/TD=\frac{\alpha}{S^{\beta}}$	S_{π}	$L/TD=\frac{\alpha}{S_{\pi}^{\beta}}$
2.94	0.90	0.383	0.63	6.52	0.54	6.52	0.55
2.44	0.90	0.383	0.63	6.52	0.45	5.24	0.55
1.94	0.90	0.383	0.63	6.52	0.36	4.07	0.55
1.44	0.90	0.383	0.63	6.52	0.27	2.94	0.55

Adjustment of Trap Days to Include Soak Time as a Measurement of Fishing Effort

"Trap days" is customarily the recorded measurement of fishing effort. This index may not accurately reflect relative fishing effort because it only records two components of fishing effort, number of traps and number of days fished. The frequency with which traps are hauled (soak time) is not reflected. Therefore, trap days is an accurate measurement of effort only as long as soak time remains constant. According to the determinants of the profit-maximizing soak time, a constant soak time seems unlikely.

One method to adjust trap days to more accurately reflect fishing effort would be according to the relationship between the number of traps and the soak time that will achieve the same total catch. Taking the total differential of Equation (5) and setting it equal to zero:

$$dL = \frac{\partial L}{\partial S}(dS) + \frac{\partial L}{\partial T}(dT) = 0 \qquad (22)$$

$$-\beta\alpha DTS^{-(\beta+1)}(dS) + \alpha DS^{-\beta}(dT) = 0 \qquad (23)$$

$$\frac{dT}{dS} = \frac{\beta T}{S}. \qquad (24)$$

Equation (24) represents the relationship between soak time and number of traps that will result in the same total catch. This relationship can be utilized to weight trap days according to soak time. The first step is to choose a base soak time (e.g., $S = 4$). When the soak time is 4 days, then the number of "adjusted traps" is equal to the number of traps and the number of "adjusted trap days" is equal to the number of trap days.

$$T^* = T - \int_4^x \frac{\beta T}{S}(dS) \qquad (25)$$

$$T^* = T + \beta T(\ln 4 - \ln x) \qquad (26)$$

$$T^*D = [T + \beta T(\ln 4 - \ln x)]D \qquad (27)$$

where T = number of traps
4 = numeraire soak time
x = prevailing soak time
T^* = adjusted number of traps
D = fishing days
T^*D = adjusted number of trap days.

When the prevailing soak time (x) differs significantly from the base soak time (4), the integration of the interval can be more accurately estimated by:

$$T^* = T \pm \sum_{S=4}^{x} \frac{\beta T}{S} \qquad (28)$$

$$T^*D = T \pm \sum_{S=4}^{x} \frac{\beta T}{S} D \qquad (29)$$

$$\text{where } x > 4 \Rightarrow \sum_{S=4}^{x} \frac{\beta T}{S} < 0$$

$$x < 4 \Rightarrow \sum_{S=4}^{x} \frac{\beta T}{S} > 0.$$

Utilizing Equations (28) and (29) and 1962 parameters, Table 2 indicates how the number of traps, trap days, adjusted traps, and adjusted trap days would compare with alternative soak times.

The interpretation of Table 2 is that the adjusted number of traps (column 5) reflects the relative fishing power of a trap at different soak times. Utilizing a 4-day soak time as a base, a trap hauled every day has 2.75 the fishing power of a trap hauled every 4 days. In the other direction, a trap hauled every 7 days has 0.54 the fishing power of a trap hauled every 4 days.

TABLE 2.—Traps, trap days, adjusted traps, adjusted trap days according to alternative soak times (base: $S = 4$).

No. traps (T)	Fishing days (D)	Trap days (TD)	Soak time (S)	Adjusted no. traps (T^*)	Adjusted no. trap days (T^*D)
1	30	30	1	2.75	82.5
1	30	30	2	1.85	55.5
1	30	30	3	1.30	39.0
1	30	30	4	1.00	30.0
1	30	30	5	0.82	24.6
1	30	30	6	0.67	20.1
1	30	30	7	0.54	16.2

Adjustment of Catch Per Trap Day to a Standardized Soak Time

Once the catch per trap day has been empirically estimated with respect to the soak time

(Equation (1)), then Equation (1) can be used to easily estimate the catch per trap day that would prevail at a standardized soak time. Comparing catch per trap day at a standardized soak time will provide a more accurate measurement of relative abundance. The relative fishing power of a trap as estimated by Equation (1) yields the same results as the computations of adjusted traps in Table 2, column 5.

Conclusions

When the soak time is variable in trap fisheries, trap days may not be an accurate index of fishing effort. Furthermore, there is evidence that as the exploitable stock declines the profit-maximizing soak time declines, which can result in a measured catch per trap day that will not reflect the declining relative abundance. It is possible to adjust trap days or catch per trap day according to the soak time to more accurately reflect fishing effort (catch per unit of effort). The calibration of this adjustment requires data on the relationship between the catch and soak time. It is recommended that in the future soak time be documented to facilitate this calibration.

Acknowledgments

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SPECIES COMPOSITION AND RELATIVE ABUNDANCE OF LARVAL AND POST-LARVAL FISHES IN THE COLUMBIA RIVER ESTUARY, 1973

Few ichthyoplankton surveys of northern Pacific coast estuaries exist: Waldron (1972) and Blackburn (1973) surveyed larvae in northern Puget Sound; Eldridge and Bryan (1972) conducted a 1-yr survey in Humboldt Bay, Calif.; Pearcy and Myers (1974) conducted an 11-yr survey in Yaquina Bay, Oreg. No data on ichthyoplankton are available for the Columbia River estuary.

In 1973, the National Marine Fisheries Service conducted a survey of zooplankton in the Columbia River estuary to study productivity and seasonal variation of zooplankton populations. The survey also captured larval and post-larval fishes. This paper reports species composition, size range, and seasonal and horizontal occurrence of larval and post-larval fishes within the Columbia River estuary. Substrate was provided for egg deposition as an additional technique to determine if spawning was occurring in the estuary. Such investigations are valuable to assessing the importance of the estuary as a spawning and nursery ground.

Methods

Seven stations from the Columbia River's mouth to Tongue Point upstream 29 km were sampled once a month with a 0.5-m plankton net January to December 1973 (Figure 1). A single station was sampled monthly from March to

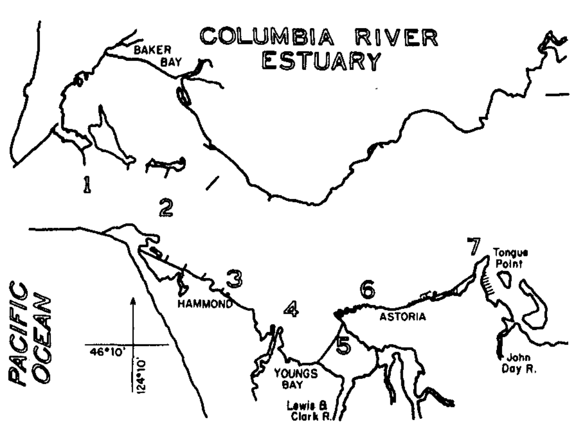

FIGURE 1.—Columbia River estuary, showing location of sampling stations.