Fishery Data Series No. 08-05

Biodegradable Twine Report to the Alaska Board of Fisheries

by

David R. Barnard

February 2008

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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The Division of Sport Fish Fishery Manuscript series was established in 1987 for the publication of technically-oriented results of several years' work undertaken on a project to address common objectives, provide an overview of work undertaken through multiple projects to address specific research or management goal(s), or new and/or highly technical methods. Since 2004, the Division of Commercial Fisheries has also used the Fishery Manuscripts series. Fishery Manuscripts are intended for fishery and other technical professionals. Fishery Manuscripts are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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ABSTRACT

Pot gear in Alaska crab and bottomfish fisheries is required to have an escape mechanism consisting of an opening closed by 100% cotton twine no larger than 30-thread. Following implementation of the Bering Sea and Aleutian Islands crab rationalization program, soak times increased in the Aleutian Islands golden king crab fishery. Due to reports of premature failure of the regulatory cotton twine in the Aleutian Islands golden king crab rationalized fishery, the Alaska Department of Fish and Game collected time-to-failure data for 30-thread twine and conducted controlled studies of the rates of biodegradation of 30-thread and 60-thread twines in seawater at Kodiak, AK. Data collected from the commercial golden king crab fishery indicated a mean time to failure for 30-thread twine of 44 days. The controlled studies provided data to estimate the tensile strengths of 30-thread and 60-thread twine as a function of time soaked using polynomial regression. Both 30-thread and 60-thread twine began to show loss of tensile strength after 2-3 weeks of soaking. The tensile strength of 60-thread twine is greater than that of new 30-thread twine through approximately the first month of soaking. Twine samples from the controlled study were intact at the end of 77 days with the 30-thread retaining 4-14% of its maximum tensile strength and the 60-thread retaining 17-19% of its maximum strength. The controlled study results are compared to previous twine degradation studies. Twine failures in the Aleutian Islands golden king crab fishery were likely due to excess forces exerted by longlined pots being retrieved from depth. Lost pots would not be subject to those forces and could require over 100 days to completely degrade allowing trapped animals to escape.

Key words: Alaska Department of Fish and Game, Aleutian Islands, crab pot escape mechanisms, cotton twine biodegradation, survival/reliability analysis, ghost fishing.

INTRODUCTION

The Bering Sea and Aleutian Islands crab-fishing industry is important to the economy of Alaska. In order to manage Alaskan crab stocks and conserve these valuable resources, the Alaska Board of Fisheries (BOF) has adopted regulations which govern how, where, and when crabs can be harvested. One such regulation (5 AAC 39.145) is designed to minimize ghost fishing by pots lost to the fishery by incorporating a biodegradable panel. Ghost fishing occurs when an unrecoverable crab or bottomfish pot continues to capture animals that, unable to escape, die of starvation or predation. This biodegradable panel regulation specifies the use of all-cotton twine to provide a time-release mechanism that affords a means of escape for animals captured by lost pots. The relevant portion of this regulation follows.

> **5 AAC 39.145. Escape mechanism for shellfish and bottomfish pots**
>
> Pot gear must include an escape mechanism in accordance with the following provisions:
>
> (1) a sidewall, which may include the tunnel, of all shellfish and bottomfish pots must contain an opening equal to or exceeding 18 inches in length, except that in shrimp pots the opening must be a minimum of six inches in length. The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread. The cotton twine may be knotted at each end only. The opening must be within six inches of the bottom of the pot and must be parallel with it. The cotton twine may not be tied or looped around the web bars.

The first statewide version of this regulation, adopted by the BOF in 1977, called for an opening in the sidewall of a pot “equal to or exceeding one half of the tunnel eye opening perimeter” to be secured by “untreated cotton twine or other natural fiber no larger than 120 thread.” No changes relevant to crab fisheries were made until 1990 when the thread count of the untreated cotton twine was reduced from 120-thread to 30-thread. This change was in part a response to losses of Tanner crabs *Chionoecetes bairdi* following the closure of the 1988 Cook Inlet Tanner crab fishery. Delinquent crab pots left on the grounds for at least 60 days following closure were responsible for the loss of an estimated 15-thousand Tanner crabs (Kimker 1990). The pots were equipped with the appropriate escape openings closed with the regulatory 120-thread twine, but the twine had not degraded to offer escape for the trapped crabs. Following this incident the Alaska Department of Fish and Game (ADF&G) conducted a series of research projects to determine the performance of cotton twine of various thread counts as a biodegradable escape mechanism for crab and bottomfish pots (Kimker 1990). This work provided the information used to specify that the twine used would be untreated 100% cotton no larger than 30 thread. Subsequent additions to 5 AAC 39.145 have provided for the use of 30-day galvanic timed-release devices in lieu of the all-cotton 30-thread twine (1993), extended the regulation to all pot gear, personal subsistence and sport use, as well as commercial (2001), and provided language to include escape mechanisms for pots with rigid mesh (2006).

With the implementation of crab rationalization in August 2005 and the establishment of the individual fishing quota system, the rationalized fishery has resulted in, among other changes, an increase in soak times for crab pots.

Beginning with the 2005/2006 crab season, ADF&G began hearing from some participants in the Aleutian Islands golden king crab *Lithodes aequispinus* fisheries of the loss of crabs due to the failure of the biodegradable twine mandated by state regulation. Reports of losses continued during the 2006/2007 season and it was communicated to ADF&G that a proposal to change the existing biodegradable-twine regulation for the Aleutian Islands golden king crab fishery would be presented to the BOF during the statewide king and Tanner Board meeting in March 2008. In order to provide information to the BOF during their consideration of that proposal, ADF&G initiated studies on the rate of biodegradation of 30-thread and 60-thread cotton twines and the time to failure for 30-thread cotton twine in the Aleutian Islands golden king crab fishery. The results of those studies are presented in this report.

METHODS

Data were collected from controlled studies conducted in Kodiak, AK and from the Aleutian Islands golden king crab fishery. Controlled studies of the rate of biodegradation were conducted by ADF&G in Kodiak from September - December 2007. Time-to-failure data were collected at sea by onboard crab observers during the 2006/2007 and 2007/2008 Aleutian Islands golden king crab fishery seasons. All of the 100% cotton twine used in these studies was purchased from local marine-supplies stores in Kodiak and Dutch Harbor; all twine was distributed by Everson Cordage Works (7180 Everson Goshen Road, Everson, WA 98247).[1]

CONTROLLED BIODEGRADATION STUDIES

Twine of two thread counts was used to assess rates of biodegradation. Twelve samples each of 30-thread and 60-thread 100% cotton twine were soaked for up to 77 days in two locations in Kodiak AK with samples collected for weekly assessment. Each twine sample consisted of a

[1] Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

continuous length of twine wound 10 times between the sides of a frame constructed of 1.3 cm (0.5 in) round aluminum bars with the frame sides spaced 61 cm (24 in) apart. The frames rested on supports keeping the twine samples suspended 15.2 cm (6 in) from the substrate. Sample collection consisted of cutting each wind once next to one bar; each collected sample consisted of ten 1.2 m (4 ft) twine strands. The 10 twine strands were held in sea water until tested at which time each strand was cut in half. One sample produced 20 replicate twine segments of approximately 61 cm (24 in) length. Testing took place within 0.5 hr of sample collection. Following International Standard CI 1500-02 established by the Cordage Institute (Cordage Institute 2006), the first sample was collected after the twine had soaked for 24 hr. Subsequent samples were collected at 3-10 day intervals.

Twine samples were soaked at two locations: the Kodiak Fisheries Research Center (KFRC) wet lab, and the city of Kodiak's St. Herman Harbor. At the KFRC wet lab location, two sample frames, one for each twine thread-count, were submerged in a covered tank, 86.4 cm (34 in) wide × 117.8 cm (70 in) long × 25.4 cm (10 in) deep, receiving a continuous supply of raw sea water at a rate of approximately 11 L/min (2.9 gal/min). The cover limited exposure to light simulating light conditions in crab fisheries and minimizing growth of epiphytes. The frames holding the samples of 30-thread and 60-thread twine were submerged in the seawater tank at the KFRC beginning on 20 September 2007. The first sample was taken after 24 hr and samples were taken weekly until the 12th and final sample was collected on 6 December 2007. Water temperatures in the tank ranged from 9.6°C on 27 September to 6.3°C on 21 November. Salinity was near constant for the duration of the study at 34-35 ppt.

In the second location, St. Herman Harbor, the sample frames for 30-thread and 60-thread twine were fastened together end-to-end and lowered to the bottom off the end of N float in approximately 15 m (50 ft) of water. Each week the frames were retrieved, the samples cut from the frames, and the frames lowered again to the bottom of the harbor. The connected frames holding the samples of 30-thread and 60-thread cotton twine began soaking on 11 October 2007. The first sample was collected 24 hr later and subsequent samples were taken weekly until the 12th and final sample was collected on 27 December 2007. Water temperatures at 2 m (6.6 ft) depth ranged from 8.1°C on 13 October to 2.8°C on 18 December. No salinity data were recorded.

The maximum load (twine tensile strength), the measurement of force applied at the time of twine failure, was measured for each twine sample using an ADMET eXpert 5601 ®[2] universal testing machine (UTM) according to standards specified by the Cordage Institute (Cordage Institute 2006). Each 61 cm (24 in) replicate was mounted on the UTM using two identical grips at each end of the twine segment. Each grip consisted of a clamp and a 2 cm (0.8 in) diameter bollard or capstan. The twine was secured to the lower grip clamp, wound 1.5 times around the lower bollard, across a 30.5 cm (12 in) free span, wound 1.5 times around the upper bollard, and secured to the upper grip clamp. The force applied to the twine sample was measured by a force cell mounted above the upper grip. The portion of the twine replicate tested for tensile strength had not been in contact with the aluminum sample frame. The UTM was programmed to apply force to the twine by moving the top grip away from the bottom grip at a constant rate of 30.5

[2] Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

cm/min (12 in/min) and to begin recording data when the exerted force equaled 2.2 newtons (N, 0.5 pounds-force (lbf)). The initial tension on the twine for each replicate was approximately 0.4 N (0.1 lbf). Force was applied until the twine failed. Recorded data used in this report were the maximum load applied at the time of failure and soak time measured in days. The recorded maximum load was interpreted as the tensile strength of the twine at the time of failure.

Regression analyses were applied to the maximum load and soak time data. Best fit was determined by examination of the residual plots for competing models, where even residual distribution indicated a better fit (Neter et al. 1996). The estimates of the parameters of the regression relationship along with model fit were computed for each twine thread count from each study location.

TIME-TO-FAILURE STUDY

Onboard crab observers were directed to collect data on the time to failure for the regulatory 30-thread cotton twine during the Aleutian Islands golden king crab fisheries. One longline pot string was selected by the observer for continuous monitoring. Each pot in the selected longline string received a uniquely-numbered tag and at the beginning of the observation period its biodegradable twine was replaced by the vessel crew with new 30-thread 100% cotton twine provided by the observer. Following the initial setting of the selected longline pot string, the observer attended all subsequent retrievals of the longline pot string. Upon retrieval the condition of the biodegradable twine on each pot was assessed and recorded by the observer. If the twine was intact the pot was reset. If the twine had failed prior to being placed on deck, or failed during deck operations, which included the crew actively testing the twine for strength, the biodegradable twine was replaced by the crew with new observer-provided 30-thread twine before the pot was reset.

Crab observer time-to-failure data were collected from one vessel fishing for Aleutian Islands golden king crabs during the 2006/2007 season and two vessels fishing for Aleutian Islands golden king crabs during the 2007/2008 season. A single longline pot string was observed on each vessel with each string being set and pulled a total of three successive times over periods of 46, 33, and 79 days. Two strings had 15 pots each and one string had 19 pots. In all, data on time to failure were collected from 60 individual biodegradable twines.

Observer-collected data were coded for survival/reliability analyses as one of three possible outcomes: exact-time failures, interval-censored failures, and right-censored failures. Exact-time failure observations occurred when the twine failed while the pot was on deck being emptied or being prepared for resetting. Interval-censored failures occurred when the twine failed between the times a pot entered the water when set and was removed from the water when pulled. Right-censored failures occurred when the biodegradable twine was still intact at the end of the study and was presumed to fail at some unobserved time after the conclusion of the study.

Survival/reliability analyses were conducted in two steps (Minitab 2005): a distribution identification analysis to select an appropriate distributional model for the data, and a parametric distribution analysis to provide an estimate of the mean time to failure. Distribution identification analyses were conducted using maximum likelihood estimation methods applied to eleven commonly used distributions: normal, logistic, exponential, Weibull, log-normal, log-logistic, 3-parameter Weibull, 3-parameter log-normal, 2-parameter exponential, 3-parameter log-logistic, and smallest extreme value. Examination of the outcomes of the distributional identification analysis for each distribution, including its Anderson-Darling score and the characteristics of plots of the survival function and the hazard function, resulted in the choice of an appropriate distributional model. Anderson-Darling scores are goodness-of-fit statistics used to discriminate between competing models. The smaller the Anderson-Darling score, the better the model fit to the data. Plots of the survival and hazard functions allow one to visually determine whether the distributional model is appropriate for the data being analyzed. In this case the survival function plot displays the probability of a biodegradable twine remaining intact past a given soak time and the hazard function plot displays the instantaneous failure rate for the twine at a given soak time.

Following the selection of a distributional model, an estimate of the mean time to failure for the observer-collected data with standard errors was computed by a parametric analysis.

RESULTS

CONTROLLED BIODEGRADATION STUDIES

KFRC Samples

There was no appreciable change in mean maximum load until 21 days soak time for the 30-thread twine and the 14 days soak time for the 60-thread twine (Table 1). Following this initial period the mean maximum load for each sample decreased with increased soak time for both twine thread counts until the end of the experiment. Neither twine degraded completely in the 77 days of exposure to seawater. The 30-thread twine still retained 14% of its maximum mean strength after 77 days and the 60-thread twine retained 19% of its maximum mean strength. After approximately 40 days soak time the 60-thread twine retained as much tensile strength as the initial tensile strength of 30-thread twine.

The regression model with the best fit for maximum load data as a function of soak time for the 30-thread twine was estimated to be a second-order polynomial (Figure 1),

$$\text{MaxLoad} = 426 - 2.14\times\text{SoakTime} - 0.0344\times\text{SoakTime}^2,\ R^2 = 0.964.$$

The regression model with the best fit for the 60-thread twine was estimated to be a third-order polynomial (Figure 1),

$$\text{MaxLoad} = 618 + 2.55\times\text{SoakTime} - 0.276\times\text{SoakTime}^2 + 0.00204\times\text{SoakTime}^3,\ R^2 = 0.971.$$

It should be noted that second-order and third-order polynomial regression models are appropriate only for the range of predictor values (soak times) used in the model (Neter et al. 1996). Using the model to make predictions outside of the established data range of soak times may result in spurious predictions.

St. Herman Harbor Samples

Similar to the results of the KFRC samples, there was no appreciable change in mean maximum load until 21 days soak time for the 30-thread twine and 14 days soak time for the 60-thread twine (Table 1). Following this initial period, mean maximum load decreased with increased soak time for both twine thread counts until the end of the study. The 30-thread twine retained 4% of its maximum mean strength and the 60-thread twine retained 17% of its maximum mean strength after 77 days of soak time. After approximately 28 days soak time the 60-thread twine retained as much tensile strength as the initial tensile strength for 30-thread twine.

Third-order polynomial regression models for maximum load vs. soak time provided the best fit to the data for both the 30-thread and 60-thread twines (Figure 2):

$MaxLoad = 456 – 0.251 \times SoakTime^2 + 0.00234 \times SoakTime^3$, $R^2 = 0.945$, for the 30-thead twine,

and

$MaxLoad = 693 – 4.40 \times SoakTime – 0.225 \times SoakTime^2 + 0.00243 \times SoakTime^3$, $R^2 = 0.966$, for the 60-thread twine.

Stepwise regression analysis resulted in the removal of the first-order SoakTime term from the model for the 30-thread twine due to lack of significance (T-value = -0.83, P-value = 0.41). Again, it should be noted that third-order polynomial regression models are appropriate only for the range of soak time values that are used in the model.

TIME-TO-FAILURE STUDY

The raw data from the 60 individual biodegradable twines in the three longlined pot strings were coded for reliability/survival analyses resulting in 9 exact-failure-time observations, 29 interval-censored observations, and 22 right-censored observations (Table 2).

Results of the distributional identification analyses yielded calculable results for 10 of the 11 potential distributional models. No variance/covariance matrix existed for the 2-parameter exponential distribution which precluded its further consideration. Based on the Anderson-Darling scores (AD) the four distributional models with the best fit to the data were, by ascending AD scores, the exponential (AD = 1.19), the 3-parameter log-logistic (AD = 1.29), the 3-parameter log-normal (AD = 1.34), and the 3-parameter Weibull (AD = 1.52). The remaining six distributional models had Anderson-Darling scores that ranged from 1.73 to 3.38. All four of the selected distributional models displayed survival function plots appropriate for the time-to-failure data. The exponential, 3-parameter log-logistic, and 3-parameter log-normal distributions were removed from consideration due to inappropriate hazard functions. The hazard function plot for the exponential distributional model indicated a constant instantaneous failure rate (Figure 3). This was interpreted as the probability of instantaneous failure being independent of soak time and therefore independent of changes in tensile strength of the twine. For the 3-parameter log-logistic and 3-parameter log-normal distributional models, the hazard function plots indicated that for soak times beyond 50 days (3-parameter log-normal) and 60 days (3-parameter log-logistic) the instantaneous failure rates would become constant and then decrease (Figure 3), i.e. – the tensile strength of the twine would at some point increase with increased soak time, an unlikely outcome. The 3-parameter Weibull distributional model, with the fourth lowest Anderson-Darling score and an appropriate hazard function plot with a constantly increasing instantaneous failure rate (Figure 3), was selected as having the best fit to the data.

Under the 3-parameter Weibull distributional model the estimated mean time to failure for biodegradable twine was 44 days (SE = 2.4) with a 95% confidence interval of 39 days to 49 days. In addition to location and scale parameters, the 3-parameter Weibull distribution included an estimated threshold parameter before which no failures would be observed. For this data the threshold parameter estimate was 20 days (SE = 2.7) with a 95% confidence interval of 14.7 days to 25.3 days. A plot of the survival function for the 3-parameter Weibull distributional model with proportions of intact twine at soak times from the observed data is displayed in Figure 4.

DISCUSSION

CONTROLLED BIODEGRADATION STUDIES

Initial studies of the degradation of cotton twine reported in Kimker (1990) consisted of testing twine of varying thread counts under different conditions, including twine installed on ADF&G survey and experimental pots, use of ADF&G-supplied twine by commercial fishers in crab fisheries, and suspending weights from samples of twine attached to a frame and soaked in a boat harbor. Of those studies the most relevant was data collected from ADF&G survey pots used in the 1990 Cook Inlet Tanner and king crab surveys. That study was conducted under close supervision and used twines that were known to be all cotton. Eight repetitions each of 30-thread, 42-thread, and 60-thread cotton twine were used to secure 46-61 cm (18-24 in) openings in 2.1 m × 2.1 m (7 ft × 7 ft) king crab pots used in the survey. The mean time to failure for the 30-thread, 42-thread, and 60-thread twines were 89 days (SE = 7.9), 101 days (SE = 6.8), and 107 days (SE = 8.7), respectively. The last twine sample, of 60-thread count, failed after 139 days of survey use and wet storage.

The results reported in Kimker (1990) are consistent with the results from the 2007 controlled biodegradation studies for 30-thread twine. While the polynomial regression models have no predictive ability beyond 77 days soak time, extending the trend observed over the last 3 weeks (56-77 days soak time) of the biodegradation study indicated the 30-thread twine soaked in the KFRC wet lab would have totally degraded by approximately 84 days soak time. The tensile strength of the 30-thread twine soaked in St. Herman Harbor had reduced to 20 N (4.5 lbf) after soaking for 77 days and extending the trend observed over the last 3 weeks of the study indicated a total loss of tensile strength at approximately 86 days. Both values were close to the mean time-to-failure estimate (89 days) for 30-thread twine from the earlier Cook Inlet study and were contained by the 95% confidence interval (74 days, 105 days) for that mean estimate. Similarly, extending the trends for the last 3 weeks (56-77 days soak time) of the 60-thread twine samples indicated total twine degradation in approximately 95 days for twine from the KFRC wet lab study and 116 days for the harbor study. Both values are contained by the 95% confidence interval (90 days, 124 days) for the estimated mean time to failure for 60-thread twine reported by Kimker (1990).

TIME-TO-FAILURE STUDY

The estimated threshold value of 20 days for the 3-parameter Weibull distributional model, indicating no failure of 30-thread twine before 20 days soak time, was consistent with results from both controlled biodegradation studies for 30-thread twine. The KFRC and St. Herman Harbor data showed no appreciable change in tensile strength for 30-thread twine prior to 21 days soak time. The combined information points to a soak time of approximately 3 weeks before which there is very little chance of failure of the 30-thread twine currently in use.

The estimated mean time to failure of 44 days for 30-thread cotton twine used in the 2006/2007 and 2007/2008 Aleutian Islands golden king crab fisheries was much less than total-degradation times reported by Kimker (1990) and those estimated from the controlled biodegradation studies reported above. This suggests that biodegradable twine failure in the Aleutian Islands crab fisheries occurred before the twine was completely degraded and still retained some portion of its original tensile strength.

Using the regression equation estimated from the controlled studies, estimates of the force exerted at the time of failure on the 30-thread biodegradable twine used in the Aleutian Islands fisheries can be calculated. Inserting the limits (39 days, 49 days) from the 95% confidence interval for the estimated mean time to failure into the equation for the 30-thread regression relationship estimated from the KFRC wet lab data resulted in estimates for tensile strengths of 290 N (65 lbf) at 39 days and 238 N (53 lbf) at 49 days. That suggests the forces applied to the biodegradable twines in the Aleutian Islands fisheries causing their failure occurred when they retained 56% to 69% of the maximum mean strength for the 30-thread twine. Tensile strengths of 290 N and 238 N for 60-thread twine are predicted to occur after 52 days soak time and 58 days soak time, respectively, by the regression equation estimated from the KFRC data. Hence, an increase from 30-thread twine to 60-thread twine would result in an increase in soak times of 3 days to 19 days before biodegradable twine failure in this fishery.

Employing the same methodology with the St. Herman Harbor controlled study, when the limits of the mean time-to-failure estimates from the observer data (39 days and 49 days) were inserted in the estimated 30-thread regression equation they produced estimates of tensile strengths of 214 N (48 lbf) at 39 days soak time and 129 N (29 lbf) at 49 soak days. That suggests that failures during the fishery occur when the twines retained 28% to 47% of their maximum strength. Tensile strengths of 214 N and 129 N for the 60-thread twine are predicted to occur after 50 days soak time and 63 days soak time, respectively, by the regression equation estimated from the St. Herman Harbor data. Hence from those data a change from 30-thread twine to 60-thread twine would be expected to increase soak times of 1-24 days before biodegradable twine failure in this fisheries.

CONCLUSIONS

The information used in the development of the regulation requiring 30-thread 100% cotton twine as the time release mechanism to prevent ghost fishing by lost crab and bottomfish pots was reported in Kimker (1990) and Kruse and Kimker (1993). Implicit in Kruse and Kimker (1993) is a defining time of 30 days as the targeted time to failure for escape mechanisms. The regulatory failure time for galvanic time-release mechanisms was also set at 30 days. That value comes from work conducted by Paul et al. (1994) and Kimker (1994). Working with Tanner crabs in a laboratory, Paul et al. (1994) found starvation of crabs for 30 days or longer affected their survival even when feeding was resumed following the starvation period. Tanner crabs held in pots and prevented from escaping began to die after 14 days and mortality increased markedly after 28 days (Kimker 1994).

It is clear that the intent of the escape mechanism regulation (5AAC 39.145) is to prevent lost crab and bottomfish pots from retaining captured crabs longer than 30 days. Controlled field and laboratory studies have shown that 30-thread 100% cotton twine remains intact for up to 105 days soak time (Kimker 1990). Larger thread-count all-cotton twine remains intact for longer soak times before total degradation. For 60-thread twine that can be as long as 125 days soak time (Kimker 1990). From the same report, 96-thread twine suspending weights in a boat harbor had 14 of 15 replicates still intact after soaking for 153 days. Canadian researchers testing different twines and cords found 120-thread all-cotton twine was still intact after 115 days soak time and still retained 24% of its original tensile strength (Scarsbrook et al. 1988). All those studies show that twines with a higher thread count require longer soak times to biodegrade.

The Aleutian Islands golden king crab fisheries have fishing conditions not experienced in the other rationalized crab fisheries. Rather than pots with individual buoy lines, multiple pots fished from longlines are used in the fishery to minimize pot loss under conditions of steep bathymetry, great depths, and strong tidal currents. Soak times have traditionally been long in these fisheries relative to the Bering Sea crab fisheries. Based on crab observer data, before crab rationalization mean soak times from the 1997/1998 to the 2004/2005 seasons have ranged from 4.0-13.4 days (Table 3), with soak times in the fishery west of 174° W longitude averaging longer than in the fishery east of 174° W longitude. Since crab rationalization mean soak times have increased, ranging from 11.5 days for the fishery east of 174° W longitude during the 2006/2007 season to 24.2 days for the fishery west of 174° W longitude during the 2005/2006 season, and instances of soak times in excess of 120 days have been recorded (Table 4). Soak times tended to be longer during the 2005/2006 season than the 2006/2007 season. In relation to two reference points from this report, the 20 soak-day threshold from the time-to-failure study and the 30 soak-day limit identified in regulation, during the 2005/2006 season, 20.8% of the soak times recorded by observers in the fishery east of 174° W longitude exceeded 20 days and 7.3% exceeded 30 days, whereas 45.9% of the soak times recorded by observers west of 174° W longitude exceeded 20 days and 28.0% exceeded 30 days. During the 2006/2007 season, 3.3% of the soak times recorded by observers in the fishery east of 174° W longitude exceeded 20 days and 0.7% exceeded 30 days. However, in the fishery west of 174° W longitude, 36.4% of the soak times recorded during the 2006/2007 season exceeded 20 days and 22.6% exceeded 30 days.

The mean time to failure of 44 days soak time estimated from observer data for 30-thread twine was considerably shorter than the 74-105 days soak time for the same twine established by Kimker (1990). It is likely that forces that result from retrieving longlined pots containing crabs under the conditions experienced in the Aleutian Islands golden king crab fishery caused some twines to fail sooner than experienced in other crab fisheries. However, the 44 day mean time to failure exceeds the 30 day soak time limit implicit in regulation by 2 weeks.

Lost pots would be exempt from the forces exerted by the retrieval process and, based on the information presented here, their biodegradable twine would remain intact for much longer. Moreover, due to the practice of longlined pots, any loss would likely be part or all of a pot string which would involve multiple pots. From the controlled biodegradation studies at KFRC and St. Herman Harbor and from the data collected in Cook Inlet (Kimker 1990), the mean time for 30-thread twine to completely biodegrade was estimated to be 84-89 days soak time. Those same studies provided estimates of 95-116 days soak time before 60-thread twine would be expected to completely biodegrade. Depending on the data set, the estimated mean time to complete biodegradation for 60-thread twine was 13%-35% greater than that for 30-thread twine. Any increase in the thread count of the biodegradable twine used for an escape mechanism for lost pots would only extend the time crabs and other animals remain trapped and lead to increased mortality.

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TABLES AND FIGURES

Table 1.–Results of tensile testing of 30-thread and 60-thread cotton twine soaked at the Kodiak Fisheries Research Center (KFRC) and St. Herman Harbor, Kodiak, AK.

			30-thread twine		60-thread twine	
Location	**Soak Time (days)**	**Number of Replicates**	**Maximum Load (N)**	**Standard Error**	**Maximum Load (N)**	**Standard Error**
KFRC wet lab	**1**	**20**	**413.2**	**5.5**	**624.4**	**7.6**
	7	**20**	**422.0**	**5.1**	**631.8**	**4.7**
	14	**20**	**408.3**	**5.4**	**584.0**	**5.0**
	21	**20**	**352.0**	**2.9**	**560.5**	**5.9**
	28	**20**	**321.0**	**3.4**	**514.0**	**5.4**
	35	**20**	**302.7**	**3.1**	**479.2**	**4.2**
	42	**20**	**287.0**	**3.9**	**408.1**	**6.7**
	49	**20**	**234.0**	**3.3**	**309.6**	**12.4**
	56	**20**	**220.2**	**4.8**	**237.0**	**7.7**
	62	**20**	**156.6**	**5.2**	**207.7**	**5.7**
	70	**20**	**95.2**	**4.5**	**134.2**	**4.0**
	77	**20**	**60.4**	**2.2**	**117.7**	**5.3**
St. Herman Harbor	**1**	**20**	**446.5**	**8.8**	**675.6**	**7.6**
	7	**20**	**456.4**	**7.8**	**664.1**	**7.5**
	14	**20**	**427.8**	**6.8**	**608.6**	**6.8**
	21	**20**	**364.8**	**8.3**	**516.2**	**9.5**
	28	**20**	**299.7**	**8.8**	**444.0**	**6.3**
	35	**20**	**244.8**	**13.2**	**380.9**	**13.7**
	41	**20**	**171.5**	**8.8**	**276.8**	**9.5**
	49	**20**	**150.7**	**14.3**	**218.0**	**10.8**
	56	**20**	**68.5**	**4.2**	**171.4**	**8.6**
	67	**20**	**46.7**	**4.7**	**127.1**	**4.6**
	70	**20**	**35.0**	**2.7**	**126.6**	**6.7**
	77	**20**	**19.8**	**2.1**	**113.3**	**5.8**

Table 2.–The resulting survival/reliability analysis coding of observer-collected data from the 2006/2007 and 2007/2008 Aleutian Islands golden king crab fishery seasons.

Type of Outcome	Start Values (days)	End Values (days)	Number of Occurrences
Exact-time Failure	22	22	1
	24	24	1
	33	33	4
	46	46	3
Interval-censored Failure	20	33	1
	22	46	9
	23	33	1
	23	48	9
	48	79	9
Right-censored Failures	9	*	1
	22	*	1
	24	*	1
	31	*	17
	46	*	1
	79	*	1

* No observed failure by the end of the study.

Table 3.–Mean soak times in days for pot lifts sampled by onboard observers during the 1997/1998 to 2004/2005 seasons of the Aleutian Islands golden king crab fishery east and west of 174° W longitude.

Season	Mean Observed Soak Time (days)	
	East of 174° W longitude	West of 174° W longitude
1997/1998	5.1	7.7
1998/1999	4.3	9.4
1999/2000	4.2	10.0
2000/2001	4.6	9.7
2001/2002	4.4	12.3
2002/2003	4.1	12.1
2003/2004	4.0	13.4
2004/2005	3.7	11.6

Table 4.–Relative frequency distribution of soak times (days) for pot lifts sampled by crab observers deployed on vessels fishing in the Aleutian Islands golden in crab fishery east of 174° W longitude and west of 174° W longitude during the 2005/2006 and 2006/2007 commercial fishery seasons.

	Percent of Sampled Pot Lifts			
	2005/2006 Season		2006/2007 Season	
Soak Time (days)	East of 174° W longitude	West of 174° W longitude	East of 174° W longitude	West of 174° W longitude
1-2	--	0.4	0.3	--
3-4	9.2	0.4	2.2	--
5-6	10.7	--	5.2	4.9
7-8	8.5	4.5	12.6	7.7
9-10	5.8	3.1	22.5	10.7
11-12	14.4	7.3	20.7	3.6
13-14	8.1	7.6	11.0	9.2
15-16	13.4	11.0	12.9	13.4
17-18	6.8	12.7	5.6	12.4
19-20	2.3	7.1	3.7	1.7
21-22	3.7	8.6	0.6	7.7
23-24	3.8	4.2	1.5	3.1
25-26	2.7	1.5	--	0.2
27-28	1.1	0.5	--	0.4
29-30	2.2	3.1	0.5	2.4
31-32	2.1	2.7	--	0.8
33-34	0.7	1.8	--	11.1
35-36	0.5	2.6	--	6.3
37-38	0.8	3.4	--	2.8
39-40	1.4	4.2	0.7	0.6
41-42	0.8	1.2	--	0.3
43-44	0.8	1.2	--	0.2
45-46	--	3.0	--	--
47-48	0.2	2.8	--	--
49-50	--	1.1	--	--
51-52	--	1.0	--	--
53-54	--	0.9	--	0.5
55-56	--	0.8	--	--
57-58	--	0.4	--	--
59-60	--	0.1	--	--
> 60	--	0.8[a]	--	--
N	1,190	1,365	1,097	1,183
Mean	14.2 d	24.2 d	11.6 d	19.0 d

[a] Three observations each of 98 d, 114 d, and 126 d soak time and two observations of 108 d soak time.

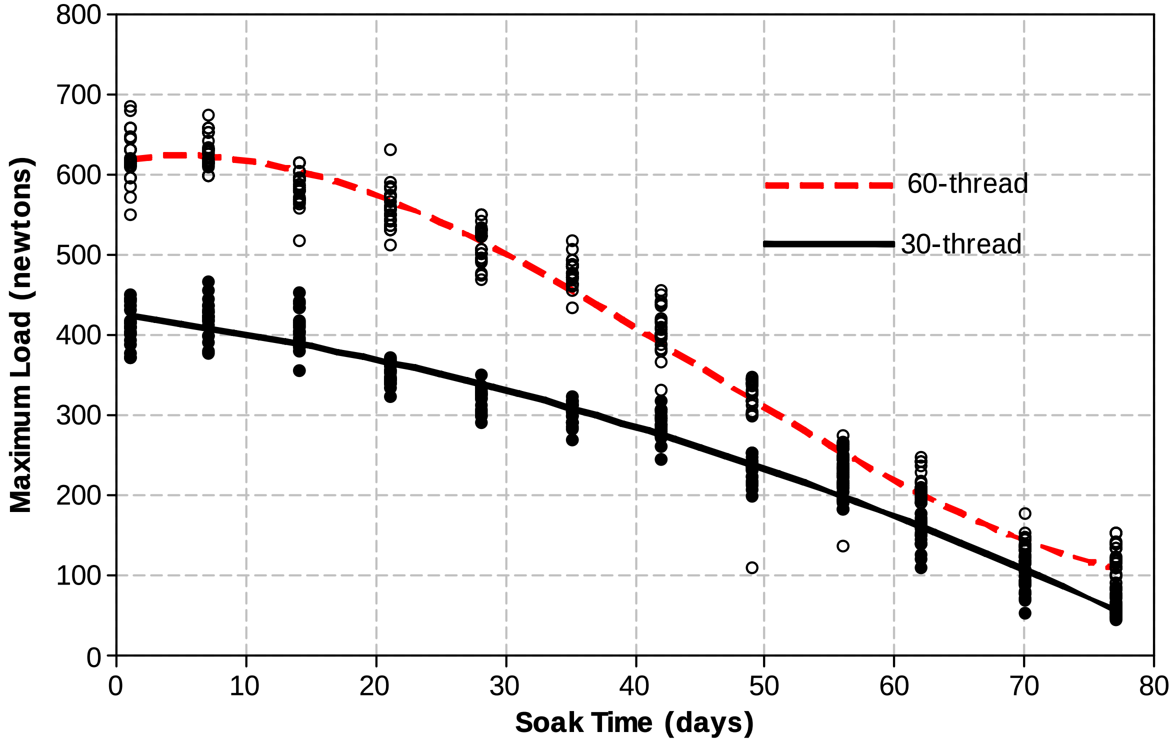

Figure 1.–Plots of the observed maximum loads for each sample along with the estimated regression relationships for maximum load as a function of soak time from the KFRC wet lab study for 30-thread (solid circles) and 60-thread (open circles) cotton twine.

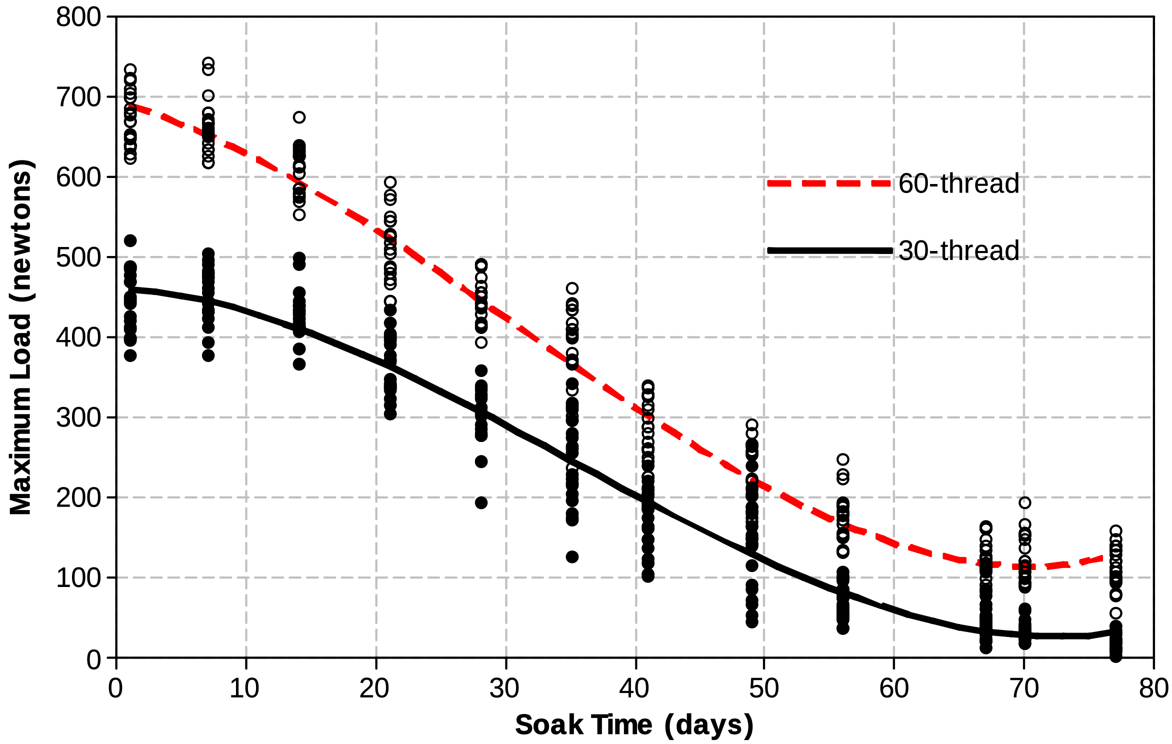

Figure 2.–Plots of the observed maximum loads for each sample along with the estimated regression relationships for maximum load as a function of soak time from the St. Herman Harbor study for 30-thread (solid circles) and 60-thread (open circles) cotton twine.

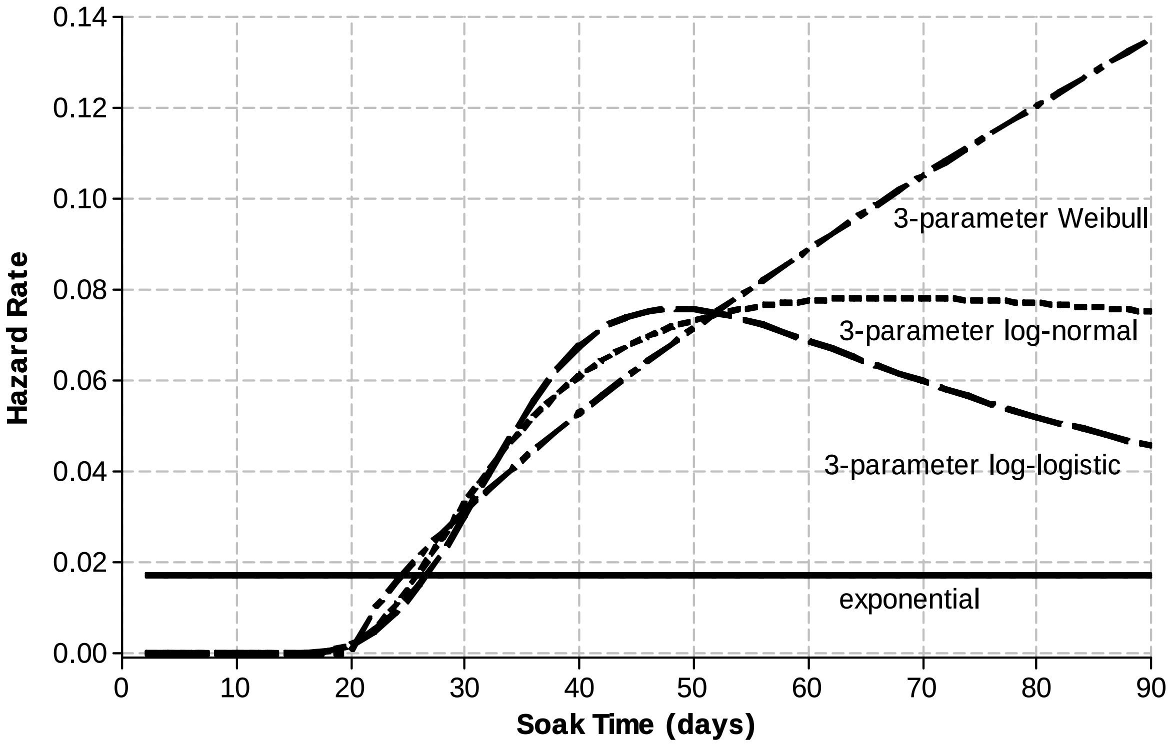

Figure 3.–Plots of the hazard functions for the exponential, 3-parameter log-logistic, 3 parameter log-normal and 3-parameter Weibull distributional models.

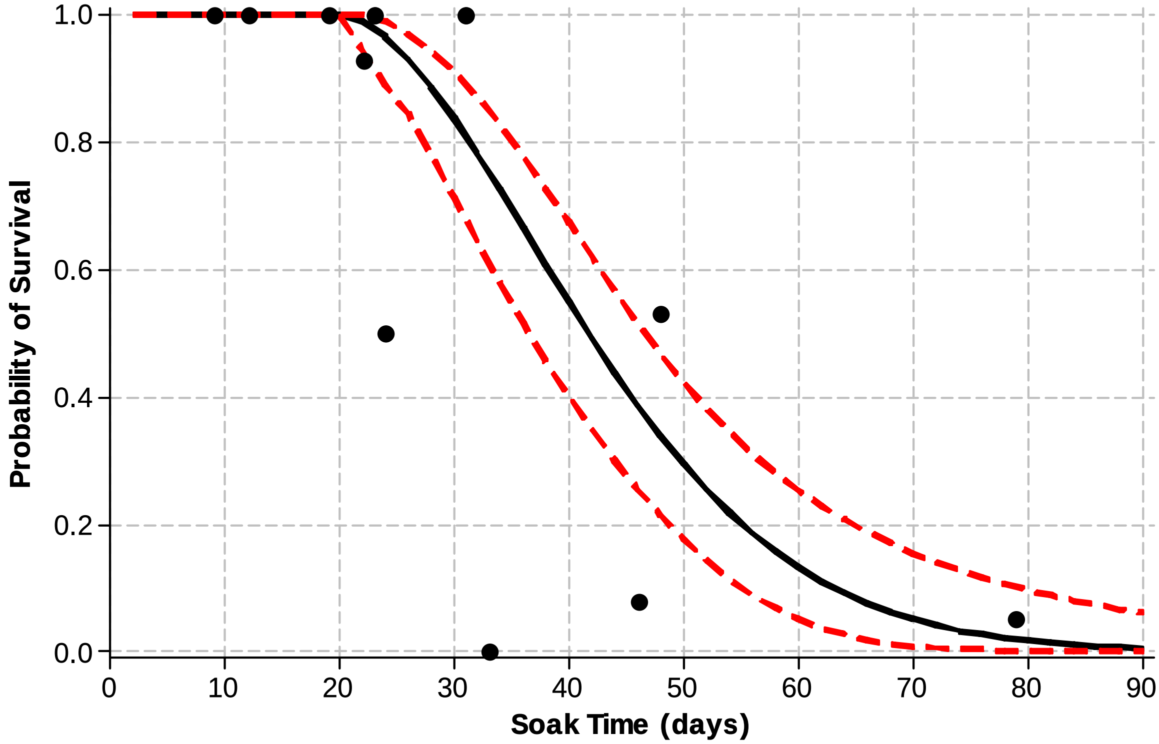

Figure 4.–Plot of the estimated survival function (solid line) along with 95% confidence limits (dashed lines) from the 3-parameter Weibull distributional model for data collected by crab observers in the 2006/2007 and 2007/2008 Aleutian Islands golden king crab fishery seasons. Included are observed proportions of intact biodegradable twine by soak time (circles) from the same data.