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Short Communication

Breaking strength evaluation of biodegradable twines to reduce ghost fishing in the pot and trap fisheries of Chile

Tomás Araya-Schmidt[1,2] & Dante Queirolo[2]
[1]Fisheries and Marine Institute of Memorial University, St. John's, Canada
[2]Escuela de Ciencias del Mar, Facultad de Ciencias del Mar y Geografía
Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile
Corresponding author: Tomás Araya-Schmidt (tomas.schmidt@mi.mun.ca)

ABSTRACT. Passive fishing gears such as pots and traps can be constructed with a section of netting made from natural fibers. In the event the fishing gear is lost or abandoned, these fibers deteriorate which effectively disables the fishing gear and allows organisms which accidentally enter the gear, an opportunity to escape without harm. This study evaluated several twines manufactured from natural fibers for their suitability to reduce ghost fishing in pots and traps. Nine cotton and jute twines of different diameters and construction were selected from Valparaiso local market, Chile. The twines were submerged for 56 days in seawater under laboratory conditions. Measurements of breaking strength were performed every 14 days. A decrease in the mean breaking strength was observed after 56 days for all twines, ranging from 0.5 to 29.6% for jute twines and 12.8 to 71.7% for cotton twines. The time until total degradation was predicted to be 113-230 days for the twisted jute twines, 68-234 for the twisted cotton twines, and 108-205 for the braided cotton twines. Our results suggest that cotton twines are a more suitable and feasible option to be implemented. The need to perform trials of biodegradable devices under commercial fishing conditions is warranted.

Keywords: ghost fishing; twine; biodegradation; escape; trap; pot

Ghost fishing is defined as the continued capture of organisms in lost, abandoned or discarded fishing gears (Macfadyen *et al.,* 2009). The phenomenon is particularly prevalent in passive fishing gears such as pots and traps (Kim *et al*., 2016). Unaccounted fishing mortality can be high in cases where the captured organisms are unable to escape. These animals die and perform the function of bait, attracting more organisms and continuing the cycle of self-baiting for years or even decades (*e.g.*, Hébert *et al*., 2001; Brown *et al.*, 2005). In Chile, pots and traps are used mainly in the lobster (*Jasus frontalis*) and golden crab (*Chaceon chilensis*) fishery of Juan Fernández Archipelago (Arana, 2012), in the mixed fishery of king crabs (*Lithodes santolla* and *Paralomis granulosa*) at the southern tip (Lovrich, 1997), and in the crab fishery along the coast of the country (Retamal *et al.*, 2009). No devices are currently used to mitigate or reduce ghost fishing in these fisheries. While there is no documented evidence on the degree of impact of ghost fishing in Chile, many agree that it is an unnecessary ecological impact and that efforts to reduce such effects are consistent with the precautionary approach to fisheries management.

Several technological innovations exist to disable fishing gears in the event they are lost or abandoned (Matsuoka *et al*., 2005). Biodegradable twines, galvanic time releases, and corrodible hog rings are among the most commonly used devices to deactivate pots and traps (*e.g.*, Scarsbrook *et al*., 1988; Kimker, 1990; Gagnon & Boudreau, 1991; Kruse & Kimker, 1993; Selliah *et al*., 2001; Redekopp *et al*., 2006; Barnard, 2008; Kim *et al*., 2014). Degradable devices are important for species conservation and produce economic benefits, considering that natural twines are a lower cost measure available to accomplish these objectives (Kruse & Kimker, 1993). Biodegradable twines are constructed of vegetable fiber thus water temperature, fiber type, rotting power of the water, and duration of immersion are the main factors that determine degradation rates (Klust, 1982; Kim *et al*., 2016).

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Table 1. Biodegradable twines selected from the local market of Valparaíso Region. Where "S" and "Z" indicate the direction of the twist, from left to right and right to left, respectively.

Twine	Diameter (mm)	Construction	Nº cords	Nº yarns per cord	Nº yarns in the core	Nº total yarns
Twisted jute 6	6.0 ± 0.4	Twisted "Z"	3	7	/	21
Twisted jute 3	3.0 ± 0.2	Twisted "S"	1	7	/	7
Twisted jute 2	2.0 ± 0.1	Twisted "S"	1	5	/	5
Twisted cotton 5	5.0 ± 0.5	Twisted "Z"	3	15	/	45
Twisted cotton 3	3.3 ± 0.2	Twisted "Z"	3	20	/	60
Twisted cotton 2	2.5 ± 0.1	Twisted "Z"	3	10	/	30
Braided cotton 5	5.2 ± 0.3	Braided	16	4	24	88
Braided cotton 3	3.0 ± 0.2	Braided	16	2	8	40
Braided cotton 2	2.0 ± 0.1	Braided	16	1	4	20

Several shellfish fisheries require the use of biodegradable netting/twine as a means to reduce or mitigate the negative effects of ghost fishing (Macfadyen *et al.*, 2009). Examples include the spiny lobster (*Panulirus argus*) fishery in Florida, that requires the use of a degradable device since 1982 (Matthews & Donahue, 1996), the king crab (*Paralithodes camtschaticus*) and the tanner crab (*Chionoecetes bairdi*) fisheries in the Bering Sea, that require an escape mechanism (Macfadyen *et al.*, 2009), the Dungeness crab fishery (*Cancer magister*) in Alaska, that requires the use of number 60 thread cotton twine or less as an escape cord in traps (Redekopp *et al.*, 2006), and the snow crab (*Chionoecetes opilio*) fishery in eastern Canada, that requires the use of 96 thread cotton twine installed in a special zipper (Winger *et al.*, 2015).

This study aimed to evaluate the degradation of different twines manufactured from natural fibers under a controlled laboratory experiment. We focused on twines that were readily available through the local market of Valparaíso, Chile, with potential application to local fisheries employing pots and traps.

A total of nine (n = 9) twine types manufactured from natural fibers were sourced from the local market of Valparaíso, Chile. These included twisted jute, twisted cotton, and braided cotton. Three diameters of each twine type were evaluated, ranging from 2.0 to 6.0 mm for jute, 2.5 to 5.0 mm for twisted cotton, and 2.0 to 5.2 mm for braided cotton: the twines varied in their type of construction (twisted or braided), in the number of cords, in the number of yarns per cord, and the number of total yarns (Table 1).

Twine samples were submerged in a flowing seawater tank (0.5 m^3) located at Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso. The twines were suspended on frames (0.5 × 0.64 m) to maintain complete immersion and effective contact with the seawater which ranged from 14.5-15.5ºC. The experiment was carried out from October 22 to December 17 of 2012. In order to quantify the loss of breaking strength (kgf) over time, a frame with a total of 10 samples of each twine type was removed at regular intervals (14, 28, 42 and 56 days), dried at room temperature for five days and assessed. Samples of the dried twines were tested using a dynamometer (Buraschi Dyna 400DP). All measurements were performed under ISO1805-2006. Due to the heteroscedasticity and non-normality observed in the exploration of the data, and heteroscedasticity shown in the residual *versus* fitted values of the Gaussian GLM model, it was decided to use the Poisson GLM, which does not assume normality or homogeneity of variance of the data. Poisson GLM (P = 0.05) was used to evaluate the effect of soak time, twine material (cotton or jute), twine construction (twisted or braided), twine diameter and a number of total yarns in the response variable breaking strength. Assumptions of independence, fixed X, no overdispersion and no patterns in the residuals were met. 'Stats' package of R statistical software (R Core Team, 2014) was used to perform the statistical analysis with the glm function. Bivariate linear regression was used to predict the value of the dependent variable (breaking strength) based on the value of the independent variable (soak time), as well as extrapolate the time until failure. In cases where breaking strength increased initially, we initiated the regression from that time forward to failure. Sigmaplot 12.0 was used to create the bivariate linear regression plots.

Initial measurements of breaking strength were collected before submersion of the twines in seawater (Day 0). Mean breaking strengths at that time ranged from 11.8 to 66.3 kgf (Table 2). Once submerged, many of the twines exhibited an initial increase in breaking strength on days 14 and 28. This increase would be due the day 0 samples were not soaked in seawater prior

Table 2. Average breaking strength (kgf), the coefficient of variation and total loss of average breaking strength of the twines. Values on parenthesis are coefficients of variation.

Twine	Average breaking strength at day					Total loss of average breaking strength (%)
	0	14	28	42	56	
Twisted jute 6	66.3 (0.13)	81.7 (0.15)	75.4 (0.16)	82.2 (0.09)	66.0 (0.10)	0.5
Twisted jute 3	33.5 (0.10)	31.0 (0.14)	35.1 (0.15)	33.3 (0.13)	29.9 (0.15)	10.4
Twisted jute 2	18.9 (0.11)	17.5 (0.17)	17.2 (0.17)	17.0 (0.2)	13.3 (0.21)	29.6
Twisted cotton 5	39.3 (0.11)	41.0 (0.17)	42.5 (0.05)	28.2 (0.14)	17.6 (0.15)	55.2
Twisted cotton 3	26.5 (0.05)	28.6 (0.04)	24.6 (0.09)	23.7 (0.05)	23.1 (0.07)	12.8
Twisted cotton 2	16.6 (0.09)	19.9 (0.05)	15.5 (0.09)	8.80 (0.12)	4.70 (0.15)	71.7
Braided cotton 5	42.4 (0.09)	42.9 (0.04)	40.2 (0.06)	36.5 (0.04)	33.6 (0.05)	20.8
Braided cotton 3	18.6 (0.02)	18.5 (0.12)	16.4 (0.07)	13.8 (0.05)	11.1 (0.03)	40.3
Braided cotton 2	11.8 (0.04)	12.3 (0.04)	10.5 (0.04)	8.60 (0.05)	6.80 (0.08)	42.4

Table 3. Initial, maximum and final average breaking strength (kgf), breaking strength loss rate and estimated time for the twine to break. *Calculated from the maximum average breaking strength value by a linear fit of the data.

Twine	Initial average breaking strength (Day 0)	Maximum average breaking strength	Final average breaking strength (Day 56)	Breaking strength loss rate (kgf day^{-1})*	Twine broke estimated time (days)*
Twisted jute 2	18.9	18.9	13.3	0.08	230
Twisted jute 3	33.5	35.1	30.0	0.18	221
Twisted jute 6	66.3	82.2	66.0	1.16	113
Twisted cotton 2	16.6	19.9	4.7	0.37	68
Twisted cotton 3	26.5	28.6	23.1	0.13	234
Twisted cotton 5	39.3	42.5	17.6	0.89	75
Braided cotton 2	11.8	12.3	6.8	0.13	108
Braided cotton 3	18.6	18.6	11.1	0.18	119
Braided cotton 5	42.4	42.9	33.6	0.22	205

testing, and may have affected the compression and rigidity of the fibers in the twines.

All of the twines experienced a reduction in breaking strength throughout the study (Tables 2-3). After 56 days in seawater, the mean reduction in breaking strength ranged from 0.5 to 71.7%. Poisson GLM results indicated that for every additional day of soak time there was a 0.5% (95% C.I. 0.4-0.6%) reduction in breaking strength. For every additional mm/unit of diameter, there was a 29% (95% C.I. 25-34%) increase in breaking strength. For every additional yarn in the twine, there was a 0.007% (95% C.I. 0.006-0.008%) increase in breaking strength.

As we move from cotton to jute twine material, we experienced a 94% (95% C.I. 80-107%) increase in breaking strength. As we move from braided to twisted twine construction, we experienced a 23% (95% C.I. 16-30%) increase in breaking strength (Table 4).

Linear regression from maximum breaking strength was used to predict the time to failure in the manner like Winger *et al.* (2015). Extrapolating the x-intercept (*i.e.*, when breaking strength reaches 0 kgf) produced predictions of 113-230 days for the twisted jute twines, 68-234 for the twisted cotton twines, and 108-205 for the braided cotton twines (Fig. 1, Table 3). Linear regressions produced the following equations that relate breaking strength and soak time for the different twines tested:

$$\text{Breaking strength (Twisted jute 2)} = -0.083 \times \text{soak time} + 19.088 \qquad R^2 = 0.248$$

$$\text{Breaking strength (Twisted jute 3)} = -0.1829 \times \text{soak time} + 40.453 \qquad R^2 = 0.178$$

$$\text{Breaking strength (Twisted jute 6)} = -1.16 \times \text{soak time} + 130.96 \qquad R^2 = 0.617$$

$$\text{Breaking strength (Twisted cotton 2)} = -0.3746 \times \text{soak time} + 25.36 \qquad R^2 = 0.961$$

$$\text{Breaking strength (Twisted cotton 3)} = -0.1254 \times \text{soak time} + 29.39 \qquad R^2 = 0.548$$

$$\text{Breaking strength (Twisted cotton 5)} = -0.89 \times \text{soak time} + 66.913 \qquad R^2 = 0.922$$

$$\text{Breaking strength (Braided cotton 2)} = -0.1313 \times \text{soak time} + 14.15 \qquad R^2 = 0.957$$

$$\text{Breaking strength (Braided cotton 3)} = -0.1774 \times \text{soak time} + 21.14 \qquad R^2 = 0.836$$

Table 4. Estimated regression parameters, standard error, Z value and *P*-value for the Poisson GLM. SE: standard error.

	Estimate	SE	Z value	*P*-value
Intercept	1.670	0.043	39.139	< 0.001
Soak time	-0.005	0.0004	-10.939	< 0.001
Twine material Jute	0.661	0.035	19.068	< 0.001
Twine diameter	0.293	0.008	36.206	< 0.001
Twine construction twisted	0.206	0.028	7.430	< 0.001
Total yarns	0.007	0.0007	9.622	< 0.001

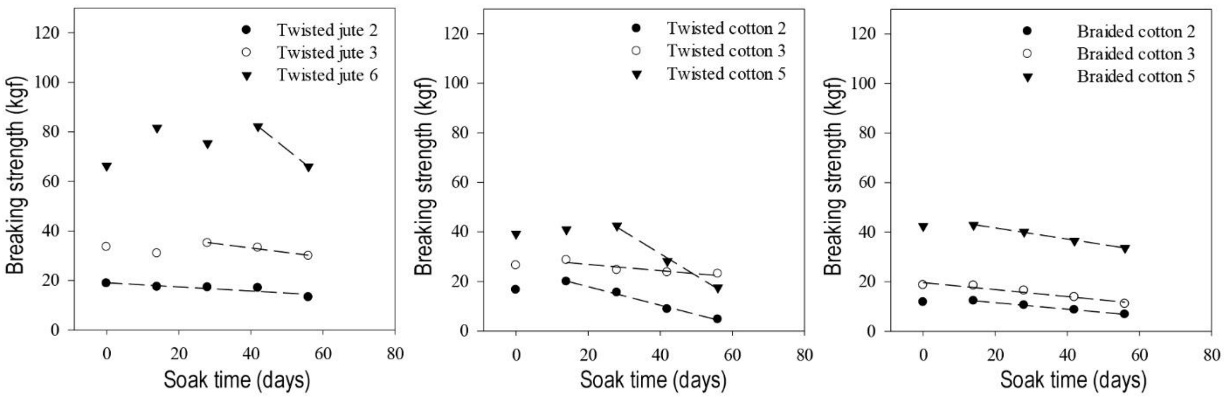

Figure 1. Breaking strength (kgf) of the biodegradable twines with increasing soak time (days) and the linear fit of the data from the maximum average breaking strength.

$$\text{Breaking strength (Braided cotton 5)} = -0.2249 \times \text{soak time} + 46.18 \qquad R^2 = 0.818$$

The results revealed that soak time had a significant effect on breaking strength. Twine properties included in the analysis (diameter, material, construction and some yarns) were significant predictors of breaking strength and affected the degradation rates. Braided and twisted cotton twines exhibited significant decay rates and low variability in breaking strength, which makes them ideal candidates for further experiments as escape mechanisms in pots and traps to reduce ghost fishing. Twisted jute twines, by comparison, exhibited lower decay rates and higher variability in breaking strength, making them poor candidates for implementation into fisheries.

In conclusion, the findings of this study suggest that braided and twisted cotton twines have the appropriate properties for further testing as a biodegradable escape mechanism in pot and trap fisheries in Chile, while twisted jute twines are unlikely to offer a solution to reduce ghost fishing. This study represents a preliminary evaluation of potential biodegradable twines to reduce ghost fishing in Chilean fisheries. Results are based solely on laboratory observations, which is a common starting point for such investigations (*e.g.*, Barnard, 2008; Matsushita *et al.*, 2008). We recommend further experiments be conducted to evaluate the decay of twines under *in situ* field conditions. Similar to Winger *et al.* (2015), the twines should be tested in the fishery in which they want to be implemented, deploying them on real fishing grounds, mounted in the traps or pots, and during the fishing season.

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REFERENCES

Arana, P.M. 2012. Recursos pesqueros del mar de Chile. Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Valparaíso, 308 pp.

Barnard, D.R. 2008. Biodegradable twine report to the Alaska board of fisheries. Alaska Department of fish and game, Division of Commercial Fisheries, Fishery Data Series 08-05, Kodiak, 19 pp.

Brown, J., Macfadyen, G., Huntington, T., Magnus, J. & Tumilty, J. 2005. Ghost fishing by lost fishing gear.

Final Report to DG Fisheries and Maritime Affairs of the European Commission. Institute for European Environmental Policy/Poseidon Aquatic Resource Management Ltd. Joint Report, 132 pp.

Gagnon, M. & Boudreau, M. 1991. Sea trials of a galvanic corrosion delayed release mechanism for snow crab trap. Canadian Technical Report of Fisheries and Aquatic Sciences, 1803: 17 pp.

Hébert, M., Miron, G., Moriyasu, M., Vienneau, R. & DeGrâce, P. 2001. Efficiency and ghost fishing of snow crab *(Chionoecetes opilio)* traps in the Gulf of St Lawrence. Fisheries Research, 52: 143-153.

Kim, S., Park, S. & Lee, K. 2014. Fishing performance of an *Octopus minor* net pot made of biodegradable twines. Turkish Journal of Fisheries and Aquatic Sciences, 14: 21-30.

Kim, S., Kim, P., Lim, J., An, H. & Suuronen, P. 2016. Use of biodegradable driftnets to prevent ghost fishing: physical properties and fishing performance for yellow croaker. Animal Conservation, 19: 309-319.

Kimker, A. 1990. Biodegradable twine report to the Alaska board of fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report Nº2H90-05, Anchorage, 10 pp.

Klust, G. 1982. Netting materials for fishing gear. FAO Fishing Manual, Fishing News Books Ltd., Farnham, UK, 177 pp.

Kruse, G.H. & Kimker, A. 1993. Degradable escape mechanisms for pot gear: a summary report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report Nº5J93-01, Anchorage, 23 pp.

Lovrich, G. 1997. La pesquería mixta de las centollas *Lithodes santolla* y *Paralomis granulosa* (Anomura: Lithodidae) en Tierra del Fuego, Argentina. Investigaciones Marinas, 25: 41-57.

Macfadyen, G., Huntington, T. & Cappell, R. 2009. Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies, Nº185. FAO Fisheries and Aquaculture Technical Paper, 523, Rome, UNEP/FAO, 115 pp.

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Matthews, T.R. & Donahue, S. 1996. By-catch in Florida's spiny lobster trap fishery and the impact of wire traps. Report submitted to the South Atlantic Fishery Management Council, 15 pp.

Matsuoka, T., Nakashima, T. & Nagasawa, N. 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fisheries Science, 71: 691-702.

Matsushita, Y., Machida, S., Kanehiro, H., Nakamura, F. & Honda, N. 2008. Analysis of mesh breaking loads in cotton gill nets: possible solution to ghost fishing. Fisheries Science, 74: 230-235.

Redekopp, R., Fisher, W., Neal, M., Velásquez, D. & Frenzl, S. 2006. Escape cord degradation rates in Port Townsend, WA. Snohomish county marine resources committee Washington State Department of Fish and Wildlife, November 1, 2006, 15 pp.

Retamal, M.A., Aedo, G., Suárez, C., Montecinos, S., Gacitúa, S., Pedraza, M. & Arana, P. 2009. Estado actual del conocimiento de las principales especies de jaibas a nivel nacional. Fondo de Investigación Pesquera, Informe Técnico FIP-IT/2007-39: 237 pp.

R Core Team. 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing. [www.R-project.org]. Reviewed: 18 March 2017.

Scarsbrook, J.R., McFarlane, G.A. & Shaw, W. 1988. Effectiveness of experimental escape mechanisms in sablefish traps. North American Journal of Fisheries Management, 8: 158-161.

Selliah, N., Oxenford, H. & Parker, C. 2001. Selecting biodegradable fasteners and testing the effects of escape panels on catch rates of fish traps. In: Creswell, R.L. (Ed.). Proceedings of the Gulf and Caribbean Fisheries Institute, 52: 634-653.

Winger, P.D., Legge, G., Batten, C. & Bishop, G. 2015. Evaluating potential biodegradable twines for use in the snow crab fishery off Newfoundland and Labrador. Fisheries Research, 161: 21-23.