THE ROLE OF DNA BARCODING TECHNOLOGY IN FISH SPECIES AUTHENTICATION: AN ECONOMIC ANALYSIS

Albert I. Ugochukwu,[1] Jill E. Hobbs[1] and Peter W.B. Phillips[2]

[1]Department of Bioresource Policy, Business and Economics, University of Saskatchewan, 51 Campus Drive Saskatoon, SK, S7N 5A8, Canada

[2]Johnson Shoyama Graduate School of Public Policy, University of Saskatchewan, 101 Diefenbaker Place Saskatoon, SK, S7N 5B8, Canada

Contact: a.ugochukwu@usask.ca

Introduction

Increasing publicized cases of fraud in fish markets has recently become a global concern, particularly to consumers, and a challenge to the food industry and regulators. Fish is a major source of protein and is traded in high volumes across the world (Anderson, 2003), with about one third of global production traded across national boundaries (FAO, 2012). Increased consumption of fish and the economic gains accruing to sellers of high-valued species have served as incentives for some members of the fish supply chain to consciously misrepresent their products for economic gains. Emerging technologies have the potential of solving this information asymmetry problem. Proper identification and truthful declaration of product attributes would protect the public from exploitation and protect the collective reputation and integrity of the fish industry. The paper focuses on the International Barcode of Life (IBOL) technology that has been used to identify plants and animal (particularly fish) species through DNA sequencing. Specifically, the paper aims to:

a) examine the incidence of species substitution and mislabelling in fish markets,

b) model private (third party) incentives to adopt the technology for supply chain monitoring, and

c) examine the feasibility of the technology for a typical retail store.

Public Concern

- Consumers cannot differentiate between similar species, especially fillets, before purchase
  - Pay premium for low-valued fish species

Farm-raised Atlantic salmon?

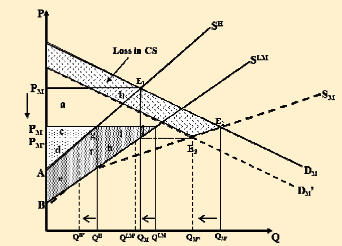
Wild-caught Pacific salmon?

- Both are different species
- Have different market values
- Can only be distinguished through testing

Source: Google images

Incidence of Species Substitution and Mislabelling

Assume a fish market with two sellers – A and B of *wild-caught Pacific* salmon



S^H = Supply curve for *wild-caught* Pacific

S^{LM} = Supply curve for *farm-raised* Atlantic

S_M = Total market supply

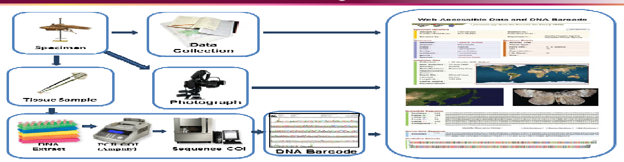
D_M = Market demand

CS = Consumer surplus

Effect of mislabelled farmed salmon entering the market for wild salmon

- At price P_M only wild-caught Pacific salmon are sold in the market, and no form of cheating
- At this price, both sellers have surplus of area *(a + b + c + d)* respectively
- To make more profit, 'B' introduced *farm-raised Atlantic* salmon, mislabelled and sold as *wild-caught Pacific*
  - Total market supply increases to $Q_{M'}$ and price reduced to $P_{W'}$
- *Wild harvesters* lose area *(a + b)* while *fish farmers* gain area *(c + d + e + f + g + h + i + j)*
- Consumers' awareness of substitution would shift demand curve to $D_{M'}$ and reduce quantity demanded to $Q_{M'}$
  - Price further reduces to $P_{M'}$
  - Creates loss in consumer surplus due to *adverse quality effect*
- If demand for wild salmon collapses, price drops to point A and the wild harvest would end

DNA Barcoding Process



Source: Floyd *et al.* (2010), Yancy (2007)

Private Incentive to Adopt DNA Barcoding Technology

- We modelled third-party (e.g. CFIA, environmental/consumer group) incentive to adopt DNA barcoding technology for **fish supply chain monitoring to catch cheaters**
- Fish supply chain comprises of suppliers/producers, processors/distributors and retailers who sell directly to consumers
- Species substitution and mislabeling potentially occur at the processor and retail levels
- Some retailers or processors potentially would cheat consumers by misrepresenting their products

Assume a distributor supplies *wild-caught* and *farm-raised* salmon to the retailer

- The retailer has two choices
  - Truthfully sell to consumers without cheating
  - Divert some farm-raised salmon, label and sell them as wild-caught to make more profit given by

$$\max_{q_W, q_F} E(\pi)\,\big|_{\alpha} = \alpha\pi_F^F + (1-\alpha)\pi_W^F\,, \alpha \in [0,1] \qquad (1)$$

Where *α = detection parameter; F = farm-raised; W = wild-caught*

- With substitution (second part of equation 1), the retailer could sell successfully or get caught when tested with DNA technology

$$\max_{q_W, q_F} E(\pi)\,\big|_{\alpha} = \alpha\pi_F^F + (1-\alpha)[\rho\pi_{nc}^F + (1-\rho)\pi_c^F] \qquad (2)$$

Where *nc = not caught; c = caught; ρ = probability of being caught*

- If not caught, he will enjoy premium (*k*) associated with *wild-caught* salmon

$$E(\pi_{nc}^F) = (P+k)\tilde{q} - C\tilde{q} - \bar{F} \qquad (3)$$

If there is a penalty for cheating (β) and other indirect costs (ω); and assume that probability of being caught cheating (ρ) depends on the accuracy of DNA technology in detecting fraud (Φ), number of fish tested at a time (λ) and leakage – no. of farmed salmon mislabeled and sold as wild ($\frac{1}{2\psi}$);

- Expected penalty for cheating becomes

$$\rho = \left[\frac{\Phi\lambda}{2\psi}\right]\beta\omega \qquad (4)$$

- If caught cheating, his profit will be

$$E(\pi_c^F) = P\tilde{q} - C\tilde{q} - \bar{F} - \left[\frac{\Phi\lambda}{2\psi}\right]\beta\omega \qquad (5)$$

- Thus, his expected net profit will be

$$\Delta E(\pi) = E(\pi_c^F) - E(\pi_{nc}^F) = P\tilde{q} - \frac{\beta\lambda\Phi\omega}{2\psi} - \tilde{q}(k+P) \qquad (6)$$

- Taking derivatives of (6) w.r.t. ***β (penalty for cheating)*** and ***ω (other indirect costs a cheater would incur if caught)***, we have

$$\frac{\partial\Delta E(\pi)}{\partial\beta} = -\frac{1}{2\psi}\lambda\Phi\omega \; < 0 \qquad (7)$$

$$\frac{\partial\Delta E(\pi)}{\partial\omega} = -\frac{1}{2\psi}\beta\lambda\Phi \; < 0 \qquad (8)$$

Equations (7) and (8) show that a legal penalty and other indirect costs (e.g. license withdrawal, reputation loss) would negatively affect a fish retailer's net profit if caught cheating by a third-party using DNA technology. This would serve as an incentive to reduce fraud and encourage truthful declaration of fish products in the market.

Feasibility of DNA Barcoding Technology

- Some retailer would like to adopt the technology to avoid being caught and protect their reputations
- Market survey data from two retail stores and costs (testing) data from Biodiversity Institute of Ontario (BIO) were used to examine the feasibility of the technology for a typical retail store in Canada

Market (store-level) data analysis for Atlantic salmon fish

Retail store	Fish type	Std weight /fish (Kg) (A)	No. of Kg sold/day (B)	No. of fish sold/day (Kg) (C)	No. of fish sold/month (D)	Ave. price/ kg sale($) (E)	Ave. price/ Fish ($/Kg) (F)	TR/month without testing ($) (G)	Price premium ($/fish)	ATC or testing /fish sample ($)
Store A	wild	1.098	30	27	820	30.99	34.03	27891.00	6.00	38.32
	farmed	1.098	30	27	820	24.99	27.44	22491.00	6.00	38.32
	total		60	55	1640			50382.00		31.01
Store B	wild	1.098	15	14	410	31.99	35.13	14395.50	6.00	46.66
	farmed	1.098	15	14	410	26.99	29.64	12145.50	6.00	46.66
	total		30	27	820			26541.00		38.18

C = B/A; D = C*30; F = A*E; G = F*D

Source: Market survey data, 2014

- We calculated the optimum testing rate beyond which retailers may not adopt the technology
  - Net revenue = total mark-up – variable costs of authentication

Store A (Large):

$(820 * 6) - [38.22 * (\delta/100) * 820]$

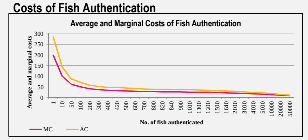
$\delta = 16\%$

Store B (Small):

$(410 * 6) - [46.66 * (\delta/100) * 410]$

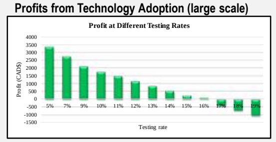
$\delta = 13\%$

Costs of Fish Authentication



Data source: BIO, 2013

Profits from Technology Adoption (large scale)



Source: Authors' calculation

CONCLUSIONS

- Increased accuracy of DNA technology in fraud detection and enforcement of legal penalties would serve as a disincentive for cheating and incentive for technology adoption by retailers in fish markets
- Currently, DNA barcoding technology appears to be feasible for a typical retail store in Canada if testing (authentication) is done in a third-party laboratory
- Testing rate of 1-13% for small and 1-16% for large retail stores would encourage adoption of the technology by retailers
- The technology may not be feasible at this time if fixed and other associated costs of the technology are considered
- Effective fish supply chain monitoring using DNA barcoding technology would enhance truthful disclosure of product (credence) attributes, and reduce market opportunistic behaviour and health risks
- Quality verification at every stage of the fish supply chain would help protect the integrity and collective reputation of the Canadian fish industry, and enable consumers make informed purchase decisions

References

1. Anderson, J.L. 2003. The International Seafood Trade. Cambridge; Woodhead Publishing
2. FAO (Food and Agricultural Organization) 2012. The state of world fisheries and aquaculture 2012. Rome.
3. Floyd, R., Lima, J., deWaard, J., Humble, L. and Hanner, R. 2010. Common Goals: Policy Implications of DNA Barcoding as a Protocol for Identification of Arthropod Pests. *Biological Invasions,* Vol. 12, pp. 2947-2954.
4. Yancy, H. F. 2007. FDA Assessment of DNA Barcoding for Species Identification of Fish

Acknowledgements

This research is supported by Alliance for Food and Bioproducts Innovation (AFBI). The Authors thank Genome Canada for providing funds to attend this conference, and also acknowledge helpful comments from Professors Richard Gray, Joel Bruneau and William Kerr. Thanks to Prof. Robert Hanner of Biodiversity Institute of Ontario., U of Guelph for his assistance.