Intro to Computer Programming
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Preliminary: Biomagnification of MeHg through trophic levels in the bay of fundy

Introduction

For our term project, we decided to study the effects of methylmercury (MeHg) biomagnification through different trophic levels of marine animals located in the Bay of Fundy. Due to the large surface area of certain aquatic organisms such as phytoplankton, MeHg, a compound of Mercury, is easily absorbed and subsequently transferred up the trophic chain through prey consumption and/or female to offspring transfer. Furthermore, MeHg is also more easily transferable up the trophic chain than inorganic mercury. Seeing as though the consumption of fish and seafood amongst humans is at an all-time high, we decided to ask the question: what initial amount of MeHg in a primary producer would eventually lead -- through biomagnification -- to human neurotoxicity if consumed? By using the trophic levels of different organisms, their average mass, amount consumed, as well as birth and death rates all while taking account the total magnification factor (dependent on their zone), we plan to computationally calculate the amount of bioaccumulated MeHG in organisms of the highest trophic order.

Test case

The values of this computational model are based on the research article "Bioaccumulation of methylmercury within the marine food web of the outer Bay of Fundy, Gulf of Maine" by Gareth Harding, John Dalziel, and Peter Vass. The scientific paper discusses the relationship between different trophic levels, size of organisms within the trophic levels and most importantly, the concentration of methylmercury (MeHg) found in the organisms.

In our project, we look duplicate the the final results through differential equations. This model can be applied to instances in which methylmercury has been introduced into an ecosystem and is transferred between organisms of different trophic levels through predator to prey consumption.

Description of Model

Seeing as though the foundation of this term project is based on the Methylmercury levels in the bay of fundy, the following equation will be used to account for the slow but constant increase in the toxin levels due to outer sources (fossil fuels, mining, etc.)

$$MeHg\ level\ final\ =\ MeHg\ initial\ \cdot 10^{0.01589T} \tag{1}$$

*where **T** is (Current year - 1800) (in years)*
*where **MeHg initial** is the aquatic concentration pre-industrial revolution (1800); 1.927 x 10^{-14}*

Primary producers such as plankton and phytoplankton are able to absorb and adsorb the MeHg found in their surrounding aquatic environment. Therefore, we must take into account their size to volume ratio which in turn relates to the total amount of MeHg that can be held within their system. The following equation is used:

$$Primary\ producer\ \ MeHg\ levels\ \ =\ \alpha \cdot\ 1.692x^{-0.344} \cdot MeHG\ level\ final \tag{2}$$

*where **α** is the bioaccumulation factor for primary producers; 1000*
*where **x** is the size of the primary producer (in nm)*

In order to calculate the final measurement of biomagnification within the organisms, we must first calculate the trophic levels of organisms. Using the δ15N of the organism (found in studies), we use the following equation to calculate the trophic level:

$$Trophic\ Level\ =\ 1\ +\ (\delta^{15}N\ organism\ + 0.03)/3.40 \tag{3}$$

By using the experimental isotopic biomagnification factor found in “study x”, we use the following formula to calculate the biomagnification through trophic levels.

$$MeHgTL_{n+1}\ = MeHgTL_{n+1} +\ (BMF_{n+1} \cdot MeHgTL_{n}) \tag{4}$$

*where **MeHgTL** is the bioaccumulation of methylmercury within a specific trophic level*
*where **BMF** is the experimental biomagnification factor, which takes into account birth rates as well as predator consumption of prey.*

The science behind the biomagnification of Mercury and its compounds.

Mercury is a chemical element that exists in many forms. While this element can occur naturally, the post-industrial revolution era has caused a rise in its levels throughout our environment. Currently, our aquatic ecosystems are suffering due to the abnormal amount of mercury (and it's compound forms) seeping into lakes, rivers and oceans.

How mercury is accumulated in the environment?

There are three main ways Mercury is introduced into an environment. Mercury can be released into the environment through natural occurrences, such as volcanoes, forest fires and the weathering of rocks. Mercury can also be released into the environment through non-natural sources, mainly the mining and burning of fossil fuels. Finally, mercury also experiences a cyclic reintroduction into the environment through the the vaporization and condensation of water.

When a compound of mercury enters an ecosystem, it is absorbed or adsorbed by an organism. This organism becomes a carrier of the element and can transfer it to other organisms through prey consumption as well as transfer from mother to offspring.

The difference between absorption and adsorption

Absorption is a process in which a substance is gradually accumulated within another substance or organism. This process occurs at a uniform rate and maintains a stable concentration throughout the material. Temperature does not affect this process.

Adsorption is a process in which a substance accumulates at the surface of another substance or organism. Unlike absorption, adsorbed substances remain only on the exterior of another surface. This rate of this process slowly increases until equilibrium is reached. Furthermore, low temperature does affect the rate of reaction.

The difference between biomagnification and bioaccumulation

Biomagnification describes the large increase in the concentration of mercury between trophic levels. This gap is created by the prey (in the lower trophic level) being consumed by the predators (residing in the upper levels). As the predators consume the prey, they also ingest their mercury, thus increasing their concentration of mercury with every bite.

Bioaccumulation occurs mainly at the first and second trophic levels, where primary producers are exposed to substances like mercury and they ingest it either through absorption or adsorption.

Description of Computational Method

In order to simulate biomagnification through organisms of different trophic levels, numerical methods were used. The constants used within the equations were taken from real-life data documented by scientific papers. The initial levels of MeHg were calculated through the use of simple system of equations.

	Ng MeHg/g	δ^{15} N of organism	Trophic Level	BMF
Trophic Level 1				
Microplankton (63um)	0.09	-0.03	1.0	N/A
Microplankton (25um)	0.05	-0.03	1.0	N/A
Trophic Level 2				
Microplankton (125um)	0.4	5.41	2.6	0.48
Mesoplankton (250um)	0.5	5.75	2.7	0.38
Mesoplankton (500um)	0.5	5.75	2.7	0.32
Trophic Level 3				
Nekton (4mm)	5.1	8.13	3.4	0.84
Blue Mussels	5.3	7.11	3.1	2.9
Sea scallops	6.9	7.11	3.1	4.0
Nekton (16mm)	17.4	9.83	3.9	2.0
Trophic Level 4				
Spiny dogfish	83.9	10.85	4.2	6.3
Atlantic Herring	54.6	11.87	4.5	3.2
Atlantic Cod	27.1	12.55	4.7	1.7
American Lobster	27.2	12.21	4.6	1.8

Results

Our early build of the simulation that is meant to recreate the biomagnification in the Bay of Fundy has yielded very promising results. We used the experimental values of BMF (Biomagnification Factors) between trophic levels, and our simulation gave us results that almost hit the mark:

	Trophic L3	Trophic L4	Trophic L5
Experimental Results (ng MeHg/g)	5.1 - 17.4	27.1 - 83.9	325.8 - 510.8
Simulated Results (ng MeHg/g)	2.6	425.2	329500

The simulated results drifted from the expected range so drastically the higher the trophic levels got because the biomagnification factors that dictate the rate of ingestion of MeHg became less representative of the trophic levels due to less data being available to us.

References

https://nereusprogram.org/works/why-is-there-so-much-mercury-in-marine-food-webs-plankton-communities-are-the-first-step-in-bioaccumulation/

https://www.des.nh.gov/organization/commissioner/pip/factsheets/ard/documents/ard-28.pdf