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Mollusc and crustacean consumption in the first 1000 days: a scoping review

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Abstract

Mollusc and crustacean consumption in the first 1000 d may improve maternal and child health by providing essential nutrients. However, in some contexts, molluscs and crustaceans have been associated with allergies and environmental contamination, potentially leading to adverse health and development outcomes. It is unclear whether the health benefits of consuming molluscs and crustaceans, collectively classified as shellfish in nutrition, are outweighed by the potential risks to pregnant women and children. We conducted a scoping review (PROSPERO: CRD42022320454) in PubMed, Scopus and EBSCO Global Health of articles published between January 2000 and March 2022 that assessed shellfish consumption during pregnancy, lactation or childhood (0–2 years) in relation to maternal health, child health or child development. A total of forty-six articles were included in this review. Overall, shellfish consumption was associated with higher biomarkers of environmental contaminants, with mercury being the most studied and having the strongest evidence base. The limited research on nutritional biomarker status shows an association between shellfish consumption and iodine status. Preterm birth was not associated with shellfish consumption, but newborn anthropometry showed mixed results, with several studies reporting lower birth weight with higher shellfish consumption. The few studies that examined child development and maternal health outcomes reported no significant associations. This review revealed trade-off health risks and benefits with inclusion of molluscs and crustaceans in the dietary patterns of mothers and young children. More research is needed to understand how these aquatic animal-source foods may be safely consumed and leveraged for improving human nutrition.

Key words: Shellfish: Pregnancy: Childhood nutrition: Iodine: Mercury

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Introduction

The first 1000 d, defined as pregnancy and the first 2 years of life, represent a period of increased nutritional demands that can have lasting health and development consequences if not met. Historically, the use of supplements has been viewed as a relatively quick and easy way to address deficiencies in vitamins and minerals. However, there is increasing concern about the health risks associated with supplement use, and global momentum to find sustainable and affordable food system solutions to micronutrient deficiencies[1]. Aquatic foods, long recognised as an excellent source of protein and essential fatty acids, have gained recent attention as a possible dietary option to promote to reduce micronutrient deficiencies, although the focus has thus far been on fish and fish products[2]. Molluscs and crustaceans, which are defined in this review as all edible shellfish, have unique nutrient profiles that differ from fish. For example, clams, mussels and oysters are remarkably rich in iron and zinc and have a more diverse nutrient profile in comparison with most aquatic and terrestrial animal-source foods[3–5]. Moreover, one global modelling study associated country-level intake of molluscs and crustaceans with reduced prevalence of childhood anaemia[6]. Thus, mollusc and crustacean consumption has the potential to address micronutrient deficiencies that are prevalent in pregnancy and early childhood while simultaneously providing high-quality proteins and essential fatty acids.

However, in areas where shellfish allergies are prevalent and water pollution is a problem, encouraging mollusc and crustacean consumption during the first 1000 d presents a dilemma. There is limited, recent evidence on the global prevalence of shellfish allergies in children. The most recent review from 2016 reports prevalence ranging from 0% to 10% across all age groups worldwide[7], and another review from the same year reports that about 0·5–2·5% of the food allergies globally may be attributed to shellfish[8]. In some countries in Asia, a region where aquatic food consumption is widespread, shellfish is the leading risk factor for anaphylaxis in older children and adults[9].

Globally, there are also concerns of environmental contamination of molluscs and crustaceans. Mercury and other heavy metals such as cadmium or lead have long been an issue, as they can bioaccumulate in aquatic foods and lead to a multitude of adverse outcomes, including reproductive harm, neurological diseases and cognitive impairment[10]. The concern of contamination has expanded to include pesticides and industrial

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compounds, many of which have been banned by the 2001 Stockholm Convention on Persistent Organic Pollutants, and more recently microplastics[11,12]. Exposure is most concerning in the first 1000 d when there is brain and organ development and rapid physical growth.

Evidence to date on health-related outcomes associated with mollusc and crustacean consumption comes largely from observational studies examining distinct nutrition or environmental contaminant outcomes. There is a need to synthesise this literature to better comprehend the trade-off risks particularly for nutritionally vulnerable periods of life. Therefore, we aimed to conduct a scoping review examining how mollusc and crustacean consumption in the first 1000 d relates to maternal and child nutrient status, health and development.

Methods

This review was conducted and is reported in accordance with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement[13,14]. The protocol for this review is registered with the University of York's International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42022320454.

Eligibility criteria

We included peer-reviewed articles reporting evidence from observational studies and interventional trials that assessed molluscs/crustaceans as a dietary exposure during pregnancy, lactation, and childhood (up to 2 years of age) in apparently healthy cohorts. In some articles, the aims were not specifically related to the first 1000 d. However, we included such articles when they included stratified analyses for our populations of interest, or when a significant proportion of the study cohort fell within our population of interest. Eligibility was also specific to consumption during the first 1000 d, regardless of when the outcomes were measured. In some cases, outcomes measured were outside of the first 1000-d window. However, if the study retrospectively assessed mollusc/crustacean consumption during the first 1000 d, we considered such studies eligible. Other studies were excluded if they studied outcomes during the first 1000 d, but retrospectively assessed periconceptional mollusc/crustacean intake (prior to pregnancy).

We further excluded studies when mollusc/crustacean intake was not assessed. In some studies, consumption of different aquatic animal foods, including molluscs and crustaceans, was assessed as exposures but outcomes were not specifically assessed in relation to mollusc/crustacean intake. Additional exclusion criteria for articles were as follows: without human subjects; without health or neurobehavioral developmental outcomes; describing outcomes for populations that were not apparently healthy (for example, populations with pre-existing allergies); not available in English; and presented as background or review papers. There were no restrictions set for the geographic location of the study. However, as environmental contamination of shellfish can fluctuate with changing policies and development, we limited our search to articles published from the year 2000 to reflect current risks and benefits.

Search strategy

We conducted our search via three electronic databases (Scopus, Medline via PUBMED, and Global Health via EBSCO). Prior to the search, the research team compiled a comprehensive list of keywords based on a pre-defined PICO framework that aligned with the review's aims. For the *population*, key terms included different synonyms or phrases characteristic of the first 1000 d, including 'child', 'infant', 'preschool', 'pregnancy' and 'lactation.' For the *intervention* or *exposure*, we identified a comprehensive list of edible mollusc/crustacean species and included them with basic keywords like 'shellfish' as well as different names of classes within the Mollusca phylum group. No search terms were developed for the *comparator,* given the likely heterogeneity in comparators across the different studies. For the *outcomes*, we identified broader MESH terms pertaining to maternal and child health as well as nutrition outcomes. We also included additional keywords based on the existing literature and some keystone papers associating aquatic animal foods with different outcomes. Terms here included markers or indicators for different heavy metal contaminants, trace and macro minerals, anthropometric outcomes, allergies and hypersensitivity. The full electronic search strategy is detailed in Supplementary Table 1. The team implemented the final search across the three databases on 23 March 2022.

Study selection

Records obtained from the databases were merged and imported to the Zotero citation management system, where duplicates were identified and removed. Subsequently, records were imported to the web-based software, Rayyan, where additional duplicates were eliminated[15]. Two reviewers (E.A.G. and E.K.) independently screened titles and abstracts of included records in Rayyan to determine eligibility for a full text review. Conflicts were then resolved by a third reviewer (B.M.O. or L.L.I.). Next, the reviewers (E.A.G. and E.K.) conducted a full text review to further determine eligibility for data extraction. Disagreements resulting from this stage were resolved through group consensus.

Data extraction

We developed a data extraction form to collect data on the following: (1) article information (first author surname; year of publication); (2) study details (study design; study aims; population description – cohort/sample description; sample size, lactating women; pregnant women; or children within the first 1000 d); (3) geographic details (country of study; World Bank income classification as a low- or middle-income country (LMIC)); (4) exposures and outcomes (molluscs/crustaceans studied; indicators/biomarkers measured; study findings). Although the studies may have reported a range of outcomes, we only reported specific indicators that were assessed in relation to shellfish consumption. Two reviewers (E.K. or E.A.G.) extracted the data, and a third reviewer (B.M.O.) subsequently validated the information collected in the data extraction form.

Nutrition Research Reviews

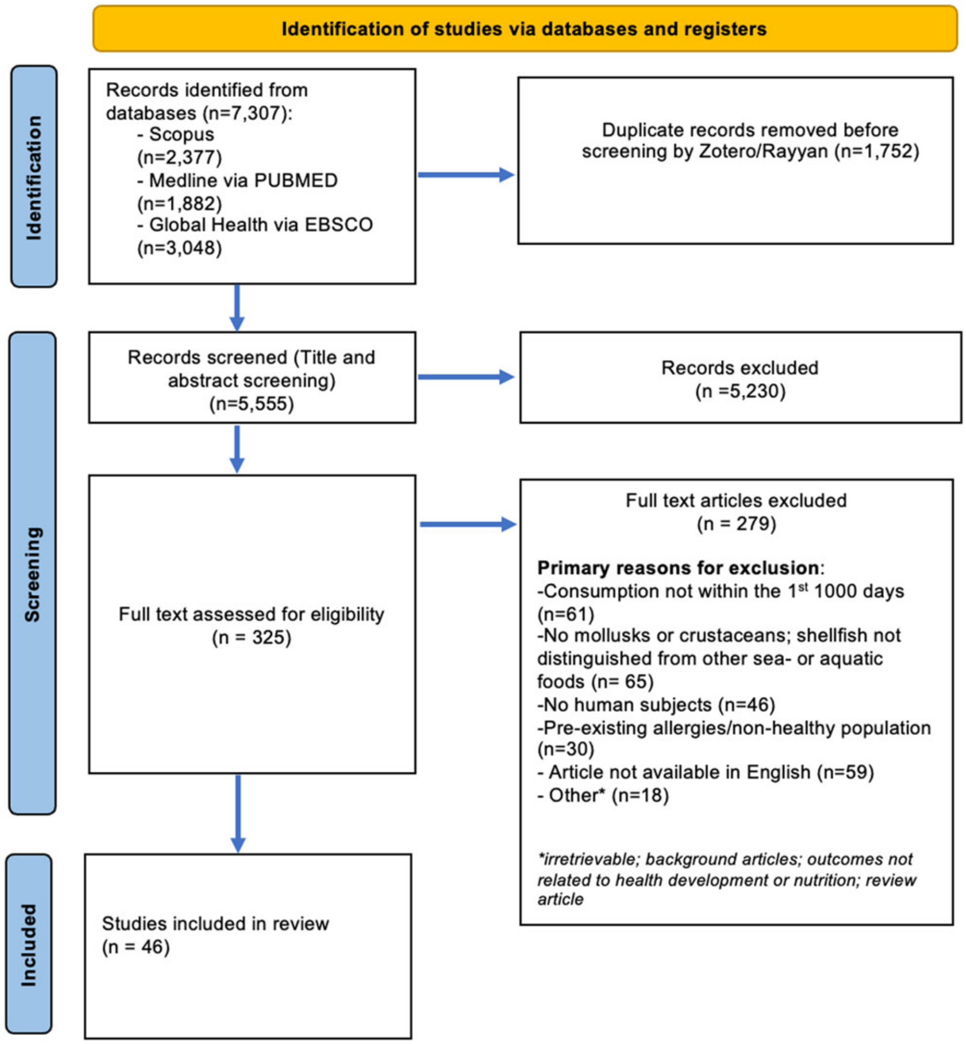

Fig. 1. Flow diagram of selection of studies for inclusion in the scoping review.

Results

A total of forty-six articles were included in this review (Supplementary Table 2). We identified 7307 articles from PubMed, Scopus and EBSCO Global Health. After removing duplicates and screening titles and abstracts for eligibility, 325 articles were assessed for inclusion by full text review. Primary reasons articles were excluded after full text review included: consumption did not occur within the first 1000 d ($n = 61$); consumption was reported in a manner that grouped mollusc and crustacean consumption with other seafood (e.g. total seafood consumption) ($n = 65$); the study did not include human participants ($n = 46$); the study was performed in a population with a specified health condition ($n = 30$); and the article was not in English ($n = 59$). See Fig. 1 for the study flow diagram.

Approximately 44% of the articles ($n = 20$) reported on pregnant women only, 15% reported on children only ($n = 7$), 30% reported on pregnant women–child dyads ($n = 14$) and 11% reported on lactating women ($n = 5$) (Fig. 2). Crustacean consumption was estimated in twenty-seven studies, with four out of these studies mentioning only crustaceans as part of their surveys, either in terms of all crustaceans, or in terms of shrimp, crab, lobster or prawn. Mollusc consumption was reported in twenty-five studies, with two out of these studies mentioning only molluscs as part of their surveys. Studies estimated total mollusc consumption or intake of specific molluscs, such as clams, mussels, cockles, scallops, oysters, squid, cuttlefish, snails and octopus. The majority of studies ($n = 40$) mentioned total shellfish consumption as a dietary exposure of interest, with twenty-three studies examining both molluscs and crustaceans and seventeen studies reporting shellfish exposures without specifying the category. In terms of reported outcomes, the number of studies reporting toxicological outcomes (heavy metals and other contaminants) ($n = 23$) was substantially greater than any other outcome in our review (Fig. 3). Most of the studies ($n = 36$) were conducted in high-income countries, primarily in the United States, Europe and Asia. No studies were conducted in Africa (Fig. 4).

Nutritional status

Iodine, fatty acids, molybdenum and selenium were the only nutrients examined in relation to shellfish consumption

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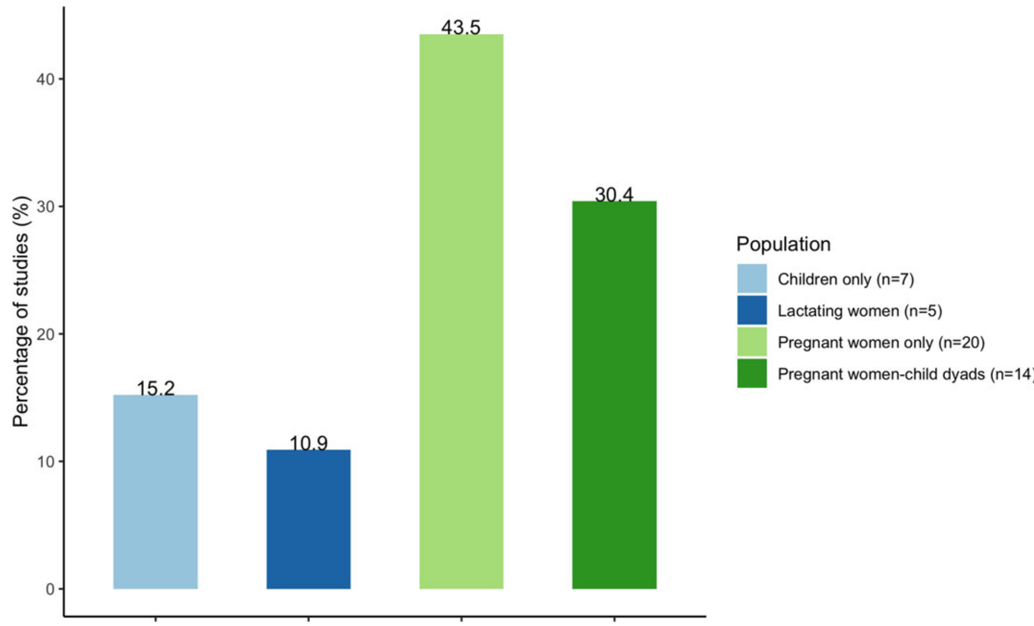

Fig. 2. Number of studies published related to maternal and child health and mollusc and crustacean consumption by study population.

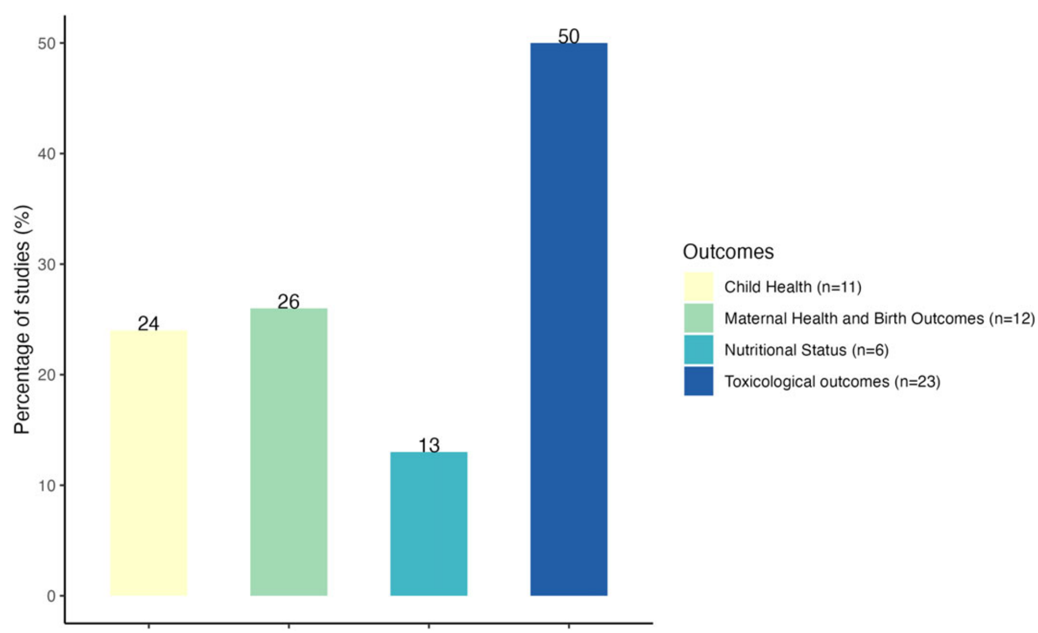

Fig. 3. Number of studies published related to maternal and child health and mollusc and crustacean consumption by outcome.

identified in this review. Three studies examined iodine (urinary iodine, $n = 2$; iodine intake, $n = 1$)[16–18], two studies examined fatty acids[19,20], one study examined urinary molybdenum and one study examined selenium in breastmilk[21]. All iodine studies were conducted among large cohorts of pregnant women[16–18]. Consuming shellfish increased the probability of meeting the iodine RDA for pregnant women[18]. Shellfish consumption increased urinary iodine concentration in one study[16] and showed a non-significant trend for increased urinary iodine concentration in a second study[17]. For fatty acids, maternal shellfish intake during the first trimester was significantly correlated with cord blood eicosapentaenoic acid concentrations, but not docosahexaenoic acid concentrations[19]. Shellfish consumption during pregnancy contributed to 2·2% of long chain n-3 polyunsaturated fatty acid intake from food in the Norwegian Mother and Child Cohort, a study that included over 60 000 pregnant women[20]. There was no significant association of shellfish intake with breast milk selenium concentration in lactating women nor urinary molybdenum in pregnant women[21].

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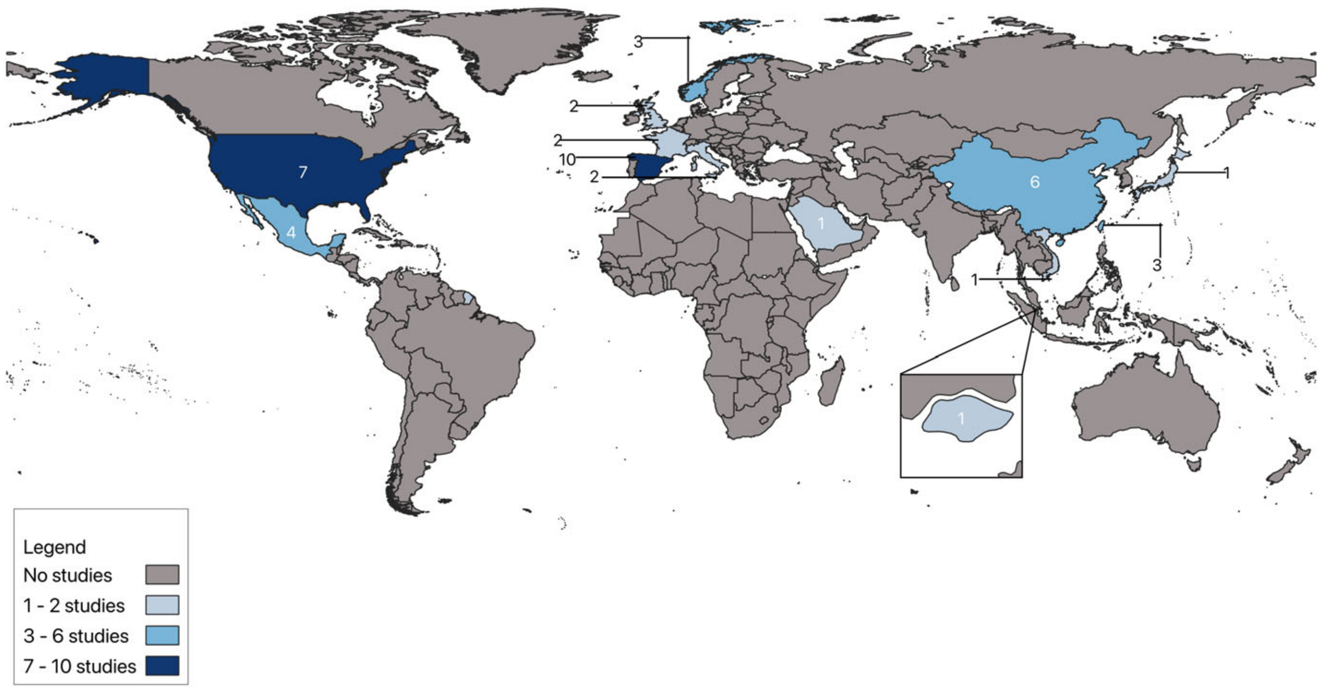

Fig. 4. Number of studies published related to maternal and child health and mollusc and crustacean consumption by country.

Summary. Overall, the present literature in relation to nutritional status suggests that shellfish consumption may be positively associated with iodine and fatty acid status but not selenium or molybdenum status. No other nutritional status indicators were examined in relation to shellfish consumption.

Maternal health and birth outcomes

Five studies measured the association of shellfish consumption during pregnancy with birth weight with mixed results[22–26]. Total shellfish consumption was associated with lower birth weight in two studies[22,23], a small cohort in Italy and the Generation R study in the Netherlands. However, total shellfish consumption was associated with higher birth weight in the large Norwegian Mother and Child Cohort study (n = 62 099 mother–infant dyads)[24], and no association in a large cohort in the United States[25]. The fifth study was conducted in Spain and observed an association of shellfish consumption with lower birth weight but reported results by shellfish category and not just total consumption. Specifically, that study of 592 mother–infant dyads reported that infants born to women with high crustacean intake and high intake of other shellfish (clams, mussels, oysters, squid, cuttlefish, octopus) had a mean birth weight that was 115 g and 91 g less than women with low intake of crustaceans and other shellfish, respectively[26]. Four of these studies also measured birth length and head circumference[22–25]. No association was found with birth length. Three of the studies found no association with head circumference[22,24,25] while one reported a non-significant trend of higher shellfish consumption with lower head circumference ($r = -0{\cdot}17$, $P = 0{\cdot}08$)[23]. One study reported a higher mean ponderal index among female infants born to women with high shellfish intake (>1 serving per week) versus women with low shellfish intake (<0·2 servings per month) (mean difference 1·1 kg/m^3, 95% confidence interval (CI) 0·3–1·9 kg/m^3) but not among male infants (mean difference 0·2 kg, 95 % CI −0·7 to 1·2 kg/m^3)[25]. One study measured foetal growth in the second and third trimester and reported no significant associations with shellfish consumption[22].

Three studies examined small-for-gestational-age (SGA), also with mixed results[22,26,27]. The Generation R study in the Netherlands reported no association of SGA with maternal shellfish consumption[22], a study in Spain (n = 592 women) reported higher risk of SGA[26], while another study in Spain (n = 518 women) reported lower risk of SGA[27]. The study that reported higher SGA risk found that maternal intake of crustacean consumption >1 serving per week was associated with increased risk of SGA (odds ratio (OR) 2·56, 95% CI 1·11–5·89) but there was no association with other shellfish intake[26]. The study reporting lower SGA risk found that compared with pregnant women that never ate shellfish, pregnant women that ate bivalve molluscs (>1 serving per week) had a 75% reduced risk of SGA (OR 0·25, 95% CI 0·08–0·76) and pregnant women that ate a serving of cephalopods one to three times a month had a 38% reduced risk of SGA (OR 0·62, 95% CI 0·44–0·87), but there was no association of SGA with crustacean consumption[27].

The relationship between shellfish consumption and angiogenic factors that influence foetal growth (placental growth factor (PIGF) and soluble Flt-1 (sFlt-1)) was assessed in the Generation R cohort and showed non-significant associations[28].

Four studies examined the association between maternal shellfish consumption and preterm birth[22,23,29,30]. Three of the studies (a small cohort in Italy, a large cohort in the United States, and the Generation R study in the Netherlands) found no association[22,23,29], and one study conducted in 10 179 pregnant women in China reported a reduced risk of preterm birth

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(OR 0·45, 95% CI 0·26–0·76)[30]. The cohort study in Italy also examined gestational duration and reported no association[23].

Four studies examined the association between shellfish consumption and maternal health[16,21,23,29]. Maternal health outcomes examined included gestational diabetes[23,29], pregnancy-induced/gestational hypertension[23,29] and pre-eclampsia[29]. No evidence of an association was found between shellfish consumption and these outcomes[23,29]. In the study that explored shellfish intake in relation to urinary iodine[16], the researchers also explored a range of outcomes related to thyroid hormones during pregnancy. They reported significant negative associations between shellfish consumption in pregnant women and isolated hypothyroxinaemia (OR 0·496, 95% CI 0·056–0·819) ($P = 0{\cdot}02$) as well as hyperthyroidism (OR 0·323, 95% CI 0·097–0·978)[16]. Associations for subclinical and overt hypothyroidism were, however, non-significant[16]. One of the studies assessing heavy metal concentrations in breast milk samples found non-significant associations between the shellfish consumption and the activity of glutathione S-transferase – an enzyme that can convert lipid-soluble toxins into water-soluble forms for excretion[31] – in breastmilk[21].

Summary. In sum, the association between shellfish consumption and birth anthropometry is inconclusive with the limited number of studies reporting both positive and negative associations with birth weight, length and head circumference. The current research suggests that shellfish consumption may reduce the risk of preterm birth, although several studies reported no association. Shellfish consumption has not been demonstrated to be associated with any primary maternal health outcomes (gestational diabetes, pregnancy-induced hypertension, pre-eclampsia), although research is limited in this area.

Child health

Child allergies and hypersensitivity were explored in nine studies, primarily in relation to shellfish consumption during pregnancy. In a large Taiwan-based cohort of children under the age of 3 years ($n = 813$), the respective prevalence of mollusc, shrimp and crab allergies were less than 1%[32]. A similar study from Singapore reported similar findings for the prevalence of shellfish allergy at ages 12, 18, 24, 36 and 48 months and found non-significant associations between the timing of shellfish introduction and the development of food allergy[33]. A US-based study also measured shellfish allergy, reporting a prevalence of less than 1% for physician-diagnosed shellfish, crustacean and mollusc allergy among children aged 0–2 years[34]. In a French study, consumption of shellfish at least once a month during pregnancy was associated with increased risk of food allergy in children at age 2 years (adjusted OR (aOR) 1·62, 95% CI 1·11–2·36), but not with wheezing or eczema[35]. One study from England reported non-significant findings in the relationship between shellfish consumption during pregnancy at varying doses and atopy as well as allergic disease at ages 3 and 10 years[36]. In a study conducted in the Netherlands, consuming 1–13 g of shellfish per week during pregnancy was also found to increase the risk of childhood wheezing (aOR 1·20, 95% CI 1·04–1·40) and eczema (aOR 1·18, 95% CI 1·01–1·37)[37].

Four of the nine studies on child allergies evaluated allergy and hypersensitivity using biomarkers of immune response. In another Taiwanese cohort, the researchers found a non-significant association between shellfish restriction up to age 12 months and IgE sensitisation (OR 1·17, 95% CI 0·67–2·04)[38]. Similar findings were reported for atopic dermatitis in this cohort (OR 1·06, 95% CI: 0·49–2·29)[38]. A study from the United States also found non-significant relationships between average shellfish intake during the first and second trimester and allergy biomarkers in early childhood[39]. One study from China explored the relationship between prenatal shellfish intake and cord blood IgE levels as well as genes implicated in the pathways for interleukins 4 and 13[40]. Generally, the researchers found no associations with the outcomes of interest. They did, however, find a gene-specific relationship for interleukin 13 (IL13); for the IL13 gene variant rs20541, statistically significant relationships were found for infants with the GG genotype[40].

Two studies examined the association between maternal shellfish consumption and child cognition[19,41]. One study additionally measured autism spectrum disorder-related traits[41], and the other study also examined parent-reported ADHD[19]. Neither outcome was associated with maternal shellfish consumption.

Summary. Overall, child allergy has been the primary focus of child health research related to shellfish consumption. In studies that examined prevalence of shellfish allergy in children, it was consistently reported as less than 1%. There is some evidence that shellfish consumption during pregnancy may be associated with an increased risk of shellfish allergy among the offspring, although there were several studies that reported no significant association. Whether shellfish consumption is related to child cognition and development cannot be determined with the limited literature, although currently no associations have been reported.

Heavy metals

Mercury concentrations in blood, hair, breastmilk or cord blood were measured in ten studies among pregnant women, lactating women and children[21,42–50]. Overall, shellfish consumption was associated with higher mercury concentrations in blood with four studies reporting higher blood mercury concentrations in association with total shellfish consumption[42,44,46,47]. A study that recruited pregnant women from a major city in each region of China reported maternal shellfish consumption during pregnancy increased the risk of foetal mercury exposure as measured in cord blood by two-fold (OR 2·21, 95% CI: 0·21–1·37)[50]. Two studies measured mercury in breastmilk[21,49]. A study in Norway examined breastmilk mercury concentrations among 300 women according to intake of crab, shrimp or mussels/scallops and showed increased intake of each category was associated with higher mercury concentrations[49]. A smaller study in Mexico reported no significant association with total shellfish consumption and breastmilk mercury concentrations[21]. Three studies examined shellfish consumption and hair mercury concentrations and reported no significant associations[43,45,48].

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A total of three studies measured arsenic status with mixed results[21,51,52]. In a study of lactating women in Mexico, arsenic concentrations in breastmilk were lower among women that ate shellfish more than once a month as compared with women that either ate shellfish less than once a month or not at all[21]. However, two studies of pregnant women (in Spain and the United States) both reported higher urinary arsenic concentrations with shellfish consumption[51,52].

Three studies measured cadmium status[49,51,53]. A study in Spain reported that squid was responsible for 28% of the cadmium intake of infants and 38% of the cadmium intake of children[53]. A study in the United States of 558 pregnant women reported no association between shellfish consumption and urinary cadmium[51]. A study in Norway of 300 lactating women showed a consistent trend of lower cadmium concentrations in breastmilk with shrimp intake, crab intake and mussel/scallop intake[49].

Only one study examined lead in relation to shellfish consumption[54]. The large cohort study was conducted in France and showed that cord blood lead concentrations were lower among infants born to women who did not consume any shellfish compared with infants born to women who consumed shellfish[54].

Summary. To summarise, mercury was the most-studied heavy metal and most, but not all, studies reported that higher shellfish consumption was associated with higher concentrations of mercury in the body. Associations with other heavy metals examined (arsenic, cadmium and lead) are inconclusive due to limited research and mixed results.

Other contaminants

Polychlorinate biphenyls (PCBs) are carcinogenic compounds used in the production of industrial and consumer products. PCBs have been banned internationally since 2001 by the Stockholm Convention on Persistent Organic Pollutants. Despite the ban, PCBs continue to affect human health due to their long half-life. Three studies have measured PCB status in relation to shellfish consumption[48,55,56]. A large cohort study of 1017 mother–infant dyads in China measured PCBs in cord blood[55], a small study of 39 lactating women in Italy measured PCBs in breastmilk[56], and a third study of 367 pregnant women in Japan measured PCBs in blood[48]. No association between shellfish consumption and PCBs was found in any of the studies[48,55,56].

Polybrominated diphenyl ethers (PBDEs) are compounds found in flame retardants and a wide array of other products, including plastics, electronics, furnishing, etc. Three studies examined whether shellfish may also be a source of PBDEs with mixed results[56–58]. A small study of lactating women in Italy reported no association between shellfish consumption and PBDE concentrations in breastmilk[56]. A study in Spain of 541 mother–infant dyads demonstrated higher PBDE cord blood concentration incrementally among infants born to women consuming shellfish[57]. In contrast, a small study of twenty lactating women in Taiwan reported lower PBDE breastmilk concentrations for women that ate shellfish nine or more times per month[58].

Bisphenol A (BPA) is an industrial compound found in polycarbonate plastics and epoxy resins[59]. In China, a study of 506 pregnant women reported that those who always consumed shellfish had significantly higher urinary BPA concentrations than those that seldom consumed shellfish[60].

Organochlorine pesticides (OCPs) are pesticides that have been extensively used in the past but, due to concerns around a long half-life and neurotoxicant and carcinogenic effects, have increasingly been banned in countries[61]. A large cohort study that enrolled pregnant women in China examined whether shellfish consumption was associated with indicators of OCP exposure in cord blood[55]. The three OCPs included in the study, all of which have been banned globally by the Stockholm Convention on Persistent Organic Pollutants, were (1) hexachlorobenzene (HCB), (2) beta-hexachlorocyclohexane (β-HCH) and (3) dichlorodiphenyltrichloroethane (DDT). No association was reported with HCB for shellfish consumption[55]. Higher shrimp intake was associated with higher cord blood concentrations of β-HCH, but no significant associations with crab intake or a group of other shellfish (oyster, clam, snail and scallop analysed together)[55]. No association was reported with DDT for shrimp or crab intake; however, higher intake of the group of other shellfish was associated with higher cord blood DDT concentrations[55]. As oyster, clam, snail and scallop were analysed as a group, it is unclear which specific mollusc is associated with higher DDT concentrations.

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds that may be carcinogenic and are produced from the burning of coal, oil, gas, wood, garbage and tobacco and cooking meat and other foods at high heat[62]. Benzo[a]pyrene (BaP) is the most-studied PAH. A study of 657 pregnant women in Spain found that, out of 24 food groups analysed, shellfish ranked as one of the top three food group predictors for BaP dietary intake and total PAH dietary intake[63].

Dioxins are a group of carcinogenic compounds produced during industrial processes and some natural processes, such as volcanic eruptions[64]. Most human exposure is due to contaminated food, primarily meat, dairy, fish and shellfish[64]. A study of 140 lactating women in Vietnam reported that women that consumed marine crab and shrimp had significantly higher concentrations of dioxins in breastmilk than women who did not consume these shellfish[65]. No other shellfish intake was examined in this study.

Perfluoroalkyl substances (PFAS) are chemical compounds that resist heat, oil, water and stains and are used as coatings on a variety of products, including furniture, non-stick cookware and food packaging[66]. PFAS have a long half-life and bioaccumulate in aquatic foods, including shellfish[67]. A large cohort study of pregnant women in Spain found that women with high shellfish intake, defined as 0·8 servings per week or more, had higher PFAS plasma concentrations than women with the lowest intake[68].

Summary. Overall, research of how shellfish consumption relates to contaminants other than heavy metals is relatively new; however, the current literature consistently suggests that higher shellfish consumptions is associated with higher concentrations of the selected contaminants (PCBs, PBDEs, BPA, OCPs, PAHs, dioxins, PFAS) studied in women and infants.

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Discussion

This review aimed to summarise the impacts of mollusc and crustacean consumption on maternal and child health and child development outcomes. Our review found that, although the literature is limited, there are some interesting trends that are emerging. Of note, shellfish consumption was consistently associated with higher concentrations of mercury in blood. Other heavy metals either had mixed results or just a single study presenting results. Research examining chemical and pesticide concentrations in humans supports shellfish as a possible source of exposure. The limited research on nutritional biomarker status suggests an association between shellfish consumption and iodine status and potentially also for fatty acids, but very few nutrients have been studied. Overall, preterm birth was not associated with shellfish consumption, but newborn anthropometry had more mixed results, with several studies reporting that higher shellfish consumption was associated with a lower birth weight. There was mixed evidence regarding shellfish consumption during pregnancy and early life on prospective risk of shellfish allergy in offspring. Lastly, the two studies that examined child development and the four studies that examined maternal health outcomes reported no significant associations.

Despite shellfish serving as a nutrient-dense food that could help address the increased nutrient needs in the first 1000 d, there were surprisingly few studies that have examined specific nutrient intake or status related to shellfish consumption, with only four nutrients investigated (iodine, fatty acids, selenium and molybdenum). Some shellfish such as oysters, clams and crab are noted for high zinc and iron concentrations[(4,5)]. As both zinc and iron deficiencies are common in the first 1000 d, it would be beneficial for future research to examine whether shellfish consumption is associated with zinc and iron status among pregnant women and children. Likewise, maternal health and child development has to date been understudied in relation to mollusc and crustacean consumption. Given the positive associations between shellfish consumption and iodine status, there is particular support for further examination of child development outcomes, as iodine status during pregnancy and early childhood impacts cognitive development[(69,70)].

When considering the forty-six studies included in this review, it was striking that none of these studies has been conducted in Africa. This is particularly important to note for a number of reasons. First, improving nutrition in the first 1000 d is increasingly identified as a public health goal for many countries in Africa, with improved nutrition as a key component[(71,72)]. Shellfish have the potential to serve as a food source for key micronutrient deficiencies that are common in Africa, such as iron and zinc, while also serving as an excellent source of protein[(4,5)]. Second, many countries in Africa struggle with environmental policy regulation and enforcement to ensure that the waters where shellfish harvesting occurs do not exceed health hazard indexes for heavy metals and other pollutants. Indeed, there have been studies in African countries that have confirmed contamination of shellfish with heavy metals and other compounds associated with adverse health outcomes[(73,74)]. Clearly, there is a compelling need to evaluate the potential trade-offs in terms of risks and benefits for shellfish nutrition in Africa.

It is also critical to note that, while the majority of the studies focused on measuring biomarkers of environmental exposures related to shellfish consumption, there was wide heterogeneity in terms of outcomes being measured. Among the twenty-seven studies that measured exposure to heavy metals or other pollutants, there were eleven different heavy metals and other pollutants that were assessed. Mercury was the only contaminant that had a strong evidence base. Arsenic[(21,51,52)], cadmium[(49,51,53)], PCB[(48,55,56)] and PBDE[(56–58)] each had three studies reporting results. The other six outcomes were supported by just a single study each. This is problematic as the issue of publication bias makes it more likely that there will be a significant association reported when only a single study has published on the topic. All six of the studies do, in fact, report a significant association, so the overall results related to environmental exposures should be interpreted with caution. However, it is critical that additional research be conducted to clarify the safety of mollusc and crustacean consumption. They are a part of many dietary patterns globally, and maintaining them as a safe food source is supportive of different cultures.

Whether shellfish consumption should be encouraged during pregnancy is still inconclusive based on our findings from this review related to preterm birth, low birth weight and SGA. Of the four studies that examined preterm birth or duration of gestation, three found no significant association[(22,23,29)]. These studies were based in Italy, the United States and the Netherlands, representing a wide range of shellfish consumption typically present in the diet. The one study that reported a significant reduction in preterm birth with higher shellfish consumption was conducted in China and had over 10 000 study participants[(30)]. This association may be due to shellfish serving as a source of omega-3 long-chain polyunsaturated fatty acids (LCPUFAs), which have been shown to reduce risk of preterm birth in randomised clinical trials[(75)]. It is unclear why the association would only be evident in China but additional research in this area is warranted. The mixed findings for low birth weight and SGA similarly are lacking any clear explanation for differing results based on geography or study size. Randomised controlled trials have shown omega-3 LCPUFA supplements during pregnancy reduce the risk of low birth weight but have little effect on SGA[(75)].

There are several strengths of this review. The primary strength is that it covered a broad spectrum of health and development indicators, including measures related both to adverse and beneficial health outcomes, to ensure this review is most useful to those working in policy and programmatic action. Further, our review was conducted according to best practices for reviews, including pre-registering our protocol, reviewing abstracts by two separate reviewers and a third when there was discrepancy, and following PRISMA guidelines for reporting. However, there are some limitations to note when interpreting the results of this review. As no studies were conducted in Africa, there is limited generalisability to that region. In addition, all studies were cross-sectional studies or cohort studies, and there were no randomised controlled trials present in the literature. There was a heterogeneity in measures of outcomes, which created difficulty in summarising the literature. Further, several outcomes that may be associated with shellfish consumption were either absent from the literature or understudied; thus,

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a lack of a reported association in this review should be understood in that context. For example, while our review found multiple articles that measured environmental contaminants in breastmilk, we found no articles that reported on shellfish allergens in breastmilk. Research on shellfish allergen detection in breastmilk and other understudied outcomes would be beneficial.

Conclusion

To our knowledge, this is the first comprehensive review of evidence focused on molluscs and crustaceans in human nutrition. We found both health benefits and risks in association with the aquatic animals consumed during the first 1000 d of life, but importantly, major gaps in the literature – including a notable lack of studies conducted in LMICs in Africa among nutritionally vulnerable populations. Studies largely came from high-income countries, with little to no evidence from nutritionally vulnerable populations. We identified minimal evidence on critical limiting nutrients such iron and zinc, despite shellfish concentrations in these important nutrients. The findings for mercury and other contaminants were concerning and merit attention by governments around the world to ensure the safety of aquatic foods. Molluscs and crustaceans hold potential for enhancing diet diversity and confronting a range of nutrient deficiencies, but there is a need to evaluate contextual factors and generate more evidence to understand the trade-off health risks and benefits, particularly for LMICs in Africa.

Supplementary material

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Data sharing

Data are available on request from the corresponding author.

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None.

Authorship

B.M.O. and L.I. conceptualised and designed the study; E.A.G. and E.K. conducted the literature search; B.M.O., E.A.G. and L.I. drafted the manuscript; B.M.O., E.A.G., K.R. and L.I. contributed to interpretation and revision of the manuscript; all authors reviewed the final manuscript.

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