Annals of Work Exposures and Health, 2020, 64, No. 8, 817–825
doi: 10.1093/annweh/wxaa055
Advance Access publication 3 June 2020
Original Article

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Occupational Asthma and Its Causation in the UK Seafood Processing Industry

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Submitted 23 September 2019; revised 23 April 2020; editorial decision 8 May 2020; revised version accepted 13 May 2020.

Abstract

Objectives: The processing of seafood (fish and shellfish) for human consumption can lead to health consequences, including occupational asthma (OA). Several non-UK studies have reported both respiratory outcomes and airborne levels of major allergens in seafood processing. However, there is a paucity of such evidence in the UK land-based seafood processing sector, which employs some 20 000 workers.
Methods: University of Manchester's Surveillance of Work-related and Occupational Respiratory Disease (SWORD) reporting system has been interrogated over the period 1992–2017 to define the incidence rate of OA cases that can be ascribed to the UK land-based processing sector, and the seafood species implicated. Airborne allergen monitoring data undertaken at Health and Safety Executive's laboratory from 2003 to 2019 have also been collated.
Results: The estimated annual OA incidence rate in seafood processors was 70 [95% confidence intervals (CIs) 48.9, 91.1] per 100 000 workers compared with 2.9 (95% CIs 2.8, 3.1) in 'all other industries'. The annual calculated percentage trend in OA (1992–2017) was −8.1% (95% CIs −15.9, 0.4) in seafood processing showing a similar trend to 'all other industries' (mean −7.0%; 95% CIs −7.8, −6.1). Prawns and salmon/trout were notably implicated by SWORD as causative species related to OA. There is a general paucity of available UK airborne allergen monitoring data, particularly concerning processing salmon or trout. Available airborne monitoring for salmon parvalbumin in seven processors ranged between the limit of detection and 816 ng m^{-3} ($n = 64$). Available air monitoring levels of the major shellfish allergen (tropomyosin) during processing of crabs and prawns ranged between 1 and 101 600 ng m^{-3} ($n = 280$), highlighting that high levels of exposure can occur.
Conclusions: These data show an excess incidence of OA in the UK seafood processing industry during 1992–2017, with limited airborne monitoring data for the processing of prawn, crab, and salmon suggesting that significant exposure to major seafood allergens can occur in this industry. Further investigation of current levels of respiratory ill-health and the sources of allergen exposure are warranted.

Keywords: allergens; asthma incidence rate; asthmagens; fish; occupational asthma; parvalbumin; seafood processing; shellfish; tropomyosin

Introduction

Occupational asthma (OA) is a disease characterized by variable airflow limitation and/or airway hyperresponsiveness due to a particular occupational environment. Two main types of OA are identified (Tarlo and Lemiere, 2014). Immunological OA develops after a latent period of exposure during which the worker acquires sensitization to the causal agent. This typically involves IgE-mediated immunological sensitization to allergenic proteins within the causal agent. Non-immunologic OA is usually due to irritant mechanisms associated with the cumulative effects of exposure to a workplace chemical. Accidental exposure to high concentrations of a workplace irritant can result in Reactive Airways Dysfunction Syndrome (RADS).

Fish and edible shellfish, both crustacean and molluscan, are widely identified as containing dietary allergenic proteins; their inclusion in foodstuffs sold for consumption legally requires warning labelling (European Commission, 2014). The major allergen in shellfish is the muscle protein tropomyosin (TM); a protein that is well conserved across crustacean species (e.g. crabs, prawns, shrimps, and lobsters) and to a lesser extent in those molluscs that are also popular edible shellfish (e.g. scallops, mussels, and whelks), with the possibility for allergic cross-reactivity between shellfish species. TM is considered a pan-allergen, as the same protein can be recognized as an allergenic protein in many other species e.g. the Der p 10 allergen in house dust mites (Shafique *et al.*, 2012). A major allergen in fish species is the protein parvalbumin (PARV), another muscle associated protein (Vázquez-Cortés *et al.*, 2010). Both TM and PARV are relatively stable proteins, possibly explaining their significance as dietary allergens even after cooking and ingestion.

Respiratory exposure to shellfish and fish in fishermen and those processing shellfish/fish for human consumption has been associated with a range of ocular and respiratory problems, including OA (Jeebhay *et al.*, 2008). Several comprehensive reviews (Jeebhay *et al.*, 2001; Jeebhay and Cartier, 2010; Lopata *et al.*, 2010; Jeebhay and Lopata, 2012; Lopata and Jeebhay, 2013) have identified potential high exposures and/or respiratory symptoms, largely based on published occupational field studies in North America, Scandinavia, other parts of Europe and Africa. A review of the international seafood industry reported a wide range of reported OA prevalence (2–36%), with a higher prevalence noted for shellfish exposure (Jeebhay and Cartier, 2010). Differences in study design, exposure scenarios, case definition, and loss of OA cases from the workplace may well have influenced these reported prevalences of OA. It is difficult from these published studies to make any inferences about the likely risk to UK seafood processors.

There is a paucity of data about health effects in the land-based UK seafood processing sector. An 8% prevalence of asthma was identified in a 1995 cross-sectional study of workers in a salmon processing plant (Douglas *et al.*, 1995). Ventilation improvements or removal from exposure led to clinical improvement on follow-up. This study also highlighted that smoking pre-disposed workers to positive serum specific IgE and asthma. A study of those exposed to *Nephrops norvegicus* (scampi) also showed an association between smoking and hypersensitivity (McSharry *et al.*, 1994). Published studies have identified other predisposing factors, such as atopy status, as reviewed by Jeebhay and Cartier (2010). An earlier UK study (Gaddie *et al.*, 1980) reported that nearly 40% of staff in a shellfish factory processing scampi (*N. norvegicus*) suffered 'asthma like' symptoms with 25% having positive skin prick tests or specific IgE results and highlighted air and water jetting methods to extract the meat from the exoskeleton as high-risk activities. Such high-risk activities have also been found to be used by crab processors to retrieve meat from the legs and led to a Health and Safety Executive (HSE) investigation of exposure in the early 2000s. However, except for three occupational studies (Gaddie *et al.*, 1980; McSharry *et al.*, 1994; Douglas *et al.*, 1995), all now over 25 years old, and a case study involving scallop (Barraclough *et al.*, 2006), there is no published UK evidence on health problems in the land-based sector processing seafood for human consumption. There is no published data estimating the incidence of OA in the sector.

'Processing' is defined as materially altering the fish/shellfish, rather than just retailing. Activities in the sector include primary processing tasks such as boiling, de-shelling, gutting, de-heading, and filleting, and secondary processing activities including producing ready meals for sale in supermarkets. It seems likely that airborne exposure to allergenic material may occur during some of these activities, as well as cleaning procedures.

This paper aims to address the paucity of published data in the UK seafood processing sector. We present data on the demographics of the sector, the asthma incidence within this sector and available aeroallergen exposure monitoring data that have been measured by the HSE's laboratory over the last 20–25 years.

Methods

Data on the demographics of the land-based seafood processing sector

Estimates of the size of the land-based processing workforce were based on published data from the Sea Fish Industry Authority, known as Seafish (see Supplementary Material, available at *Annals of Work Exposures and Health* online edition).

Data on OA incidence

The Health and Occupation Research Network (THOR) is based at the University of Manchester and is a research and information dissemination programme on the incidence and health burden of occupational disease and work-related ill-health. Reporting to the Surveillance of Work-related and Occupational Respiratory Disease (SWORD) involves chest physicians who voluntarily report newly diagnosed cases of work-related respiratory disease, seen during their reporting month(s) that they judge to have been caused or aggravated by work. Participation is for either 1 (randomly selected) month per year ('sample' reporters) or for 12 months a year ('core' reporters) (Meredith *et al.*, 1991). Data are available for the period 1989–2015, although analyses for trends are performed from 1992 when a consistent and stable reporting system had been established.

A text search for appropriate cases within SWORD database was undertaken using the following search terms: fish, seafood, shellfish, prawn, shrimp, crab, lobster, crayfish, scampi, scallop, whelk, cockle, salmon, tuna, cod, haddock, plaice, herring, mackerel, and sardine. Reports that were related to fishing or fish farming were excluded from further analysis as not within the definition of the processing sector. Reported cases of respiratory disease other than OA were also noted.

Annual average incidence rates of OA (per 100 000 persons, per year) were calculated for the land-based seafood processing industry and compared with the rate for all other industries combined. The numerator was the number of cases reported to SWORD (1992–2017) adjusted for sampling frequency (i.e. 'core' and 'sample' reporting), the proportion of physicians reporting to SWORD, and the proportion responding during their reporting month (Carder *et al.*, 2011). The denominator was the estimate of workers likely to be exposed, as derived from Seafish reports. Approximate 95% confidence intervals (CIs) were calculated using a first-order Taylor linearized variance estimator to take into account specific characteristics of the data for example, the weighted sampling adjustments to the numerator (Wolter, 2007).

Trends in the incidence of OA (1992–2017) were investigated using a method previously applied to SWORD data whereby the STATA software command xtnbreg was used to fit a two-level longitudinal, negative binomial (i.e. overdispersed) model with random effects. This method allows for variation in the number of reports between physicians (e.g. core versus sample and due to non-response) (McNamee *et al.*, 2008). The dependent variable was the number of actual cases, including zeros (a physician not seeing any relevant cases during their reporting month should notify SWORD to this effect), per reporter per month. The main predictor of interest, calendar time, was represented as a continuous variable with a scale of years. Variables representing other potential confounders were also included (McNamee *et al.*, 2008). To account for changes in population base an offset variable representing the population each year (i.e. 1992–2017) was included.

Aeroallergen exposure monitoring data

HSE's laboratory had developed an immunoassay for measuring airborne levels of shellfish muscle protein in the early 2000s. This assay was very broadly cross-reactive across the common edible crustacean species. In 2015, HSE produced its own antiserum against purified shrimp TM and developed a polyclonal sandwich immunoassay. This TM-specific assay showed that the earlier 'shellfish muscle protein' assay was largely measuring TM; the specific TM assay giving results that were generally 20% lower than the old assay. In 2017, HSE purified PARV from North Atlantic salmon, raised polyclonal antisera against it and developed a non-competitive, sandwich immunoassay (paper in preparation). This salmon PARV assay also shows good cross-reactivity with rainbow and brown trout, but not other fish species tested. The analytical limit of detection for the assays (0.1 ng ml^{-1} for TM and 0.5 ng ml^{-1} of PARV) approximates to an airborne concentration of approximately 0.4 and 2 ng m^{-3} for full-shift sampling at 2 l min^{-1} for TM and salmon PARV, respectively.

HSE undertook a small-scale monitoring study of eight crab processors during 2003–2006. This was due to concerns about using air/water jetting to remove meat from parts of the exoskeleton (Gaddie *et al.*, 1980) and the potential to generate large aerosols of allergenic material. These airborne monitoring data were supplemented by commercial air monitoring data undertaken in shellfish units by occupational hygienists and analysed by HSE's laboratory during 2003–2017. The immunoassay for salmon PARV has been employed in 2016–2019 in commercial air monitoring of seven salmon processors.

Where concentrations of allergen measured in extracts of the filters were at, or below, the assay's limit of detection (LOD), a notional airborne exposure was calculated using a value of half the analytical LOD adjusted for the air volumes sampled. The shellfish results were brigaded into work task categories based on the information supplied with individual air samples.

Results

Demographics

In 2016 we estimate that some 20 000 workers may have undertaken work within the UK land-based seafood processing sector, having declined from a peak in around 2000 (see Supplementary Table S1, available at *Annals of Work Exposures and Health* online edition). The size of the fish/shellfish processing industry can be compared with the overall size of the UK food and drink manufacturing sector of some 400 000 workers in 2016 (Noble *et al.*, 2016; Food and Drink Federation, 2018).

Incidence cases of respiratory ill-health reported to SWORD 1992–2017

Ten cases were excluded from the initial SWORD search as associated with fishing or fish farming rather than the seafood processing sector, although some tasks associated with primary processing (principally de-heading, gutting, and filleting) may also occur on vessels and salmon/trout farms.

From 1992 to 2017, 62 respiratory cases were retrieved from the SWORD system as related to the seafood processing sector, 58 (94%) of these cases were in the OA diagnostic category. This equates to an estimate of 190 OA cases during 1992–2017. The remaining reported cases were isolated cases of allergic alveolitis (prawn) and respiratory irritation (scampi), and two cases of inhalation incidents (chlorine).

Table 1 shows the estimated annual incidence of OA in the fish and shellfish processing sector over the period 1992–2017 in comparison with 'all other sectors'. The data suggest a 24-fold OA excess over the period in the seafood processing sector. While 94% of the total respiratory cases in the seafood sector were OA, only 16% of the estimated total respiratory disease was OA in 'all other sectors' (data not shown). This suggests that not only is there an excess of OA but it is a predominant respiratory disease in the seafood processing sector. The decreasing trend in OA over the period for the seafood sector appears statistically significantly higher than that for all other sectors (Table 1), but the means are only marginally different and the CI for the seafood sector is wide.

The agents implicated in the 58 cases of OA reported to SWORD are shown in Table 2. The majority of these attributed, causative agents relate to shellfish or fish species. The largest implicated exposure was to prawns. Interestingly a large majority of asthma cases related to fish exposure were ascribed to salmon and/or trout that are farmed fish. Five cases suggest an irritant exposure (smoking agent, sulphur dioxide, and metabisulphite) as the cause of OA. Supplementary Table S2 (available at *Annals of Work Exposures and Health* online) gives data on the amounts landed, imported and exported of various seafood species, giving some idea of the tonnages processed in the UK. While prawns and shrimps are included together in this data, the tonnages appear

Table 1. 1992–2017 SWORD data on number and estimated asthma cases, the annual incidence rate and trend over time.

	Number of actual (estimated[a]) asthma cases	Annual average asthma incidence rate (95% CIs) per 100 000, per year	Annual average percentage change in asthma incidence (95% CIs)[b]
Fish and shellfish processing	58 (190)	70 (48.9, 91.1)	−8.1 (−15.9, 0.4)
All other industries	4308 (9951)	2.9 (2.8, 3.1)	−7.0 (−7.8, −6.1)

[a]Chest physicians report voluntarily to SWORD for either 1 (randomly selected) month per year ('sample' reporters) or for 12 months a year ('core' reporters). 'Actual' = ('sample' cases + 'core' cases); 'Estimated' =12 × 'sample' cases, + 'core' cases.

[b]Tests for significance suggested that the two trends (fish and shellfish processing versus all other industries) were statistically different for asthma ($P < 0.001$).

predominant amongst shellfish and consistent with prawns being attributed to most cases of OA. Salmon is processed in high tonnages in the UK, but even more cod is processed without appearing to be specifically implicated as a causative agent. Interestingly trout is processed in relatively low amounts. Therefore, the causation does not seem necessarily a simple reflection of the relative tonnages processed.

Table 2. Agents associated with asthma cases reported to SWORD (1992–2017).

Agent(s) implicated	Number of cases
Shellfish	
Prawns	22
Crab	2
Crab or prawns	1
Scampi	1
Shrimp	1
Scallop or prawns	2
Crustacea (unspecified)	1
Fish	
Salmon or trout	9
Salmon	6
Trout	4
Fish (unspecified)	3
Other agents	
Smoking agent	1
Sulphur dioxide	1
Coating crumb	1
Metabisulphite	3

Aeroallergen exposure monitoring data

HSE's laboratory undertook 329 shellfish measurements in air samples from 24 UK units during 2003–2017. Two hundred and ninety-one samples had information on air volumes sampled that allowed calculation of airborne concentrations. Measurements related to crab processing (64%), prawn (29%) and scampi (3%). One hundred and eleven of the crab monitoring samples were taken from 8 units during 2003–2006 as part of an HSE study.

Table 3 shows the median and range of airborne TM levels (ng m^{-3}) for all monitoring activity during 2003–2017 and by shellfish species. The TM exposure monitoring data are highly skewed to the right for all values and from monitoring exposure to crab or prawns. A breakdown of TM aeroallergen levels for the 2003–2006 crab study are also shown in Table 3, where it was possible to brigade information on tasks to try and identify where high exposures were found. Where crab legs have been blown with air or water jets to extract the crab meat, the limited data in Table 3 indicate that automated systems for 'blowing' can still produce high levels of airborne allergen. Again on limited data, using electric circular saws on crab shells or their claws can also produce significant allergen aerosols. Allergen aerosols from crab processing are much lower outside of processing rooms such as 'raw/live' storage and post-processing packing areas.

In the period 2017–2019, 64 measurements of airborne salmon PARV were undertaken from 7 salmon processors, ranging from non-detected to 816 ng m^{-3} with a median of 43 ng m^{-3} and a 90th percentile of

Table 3. Available data on airborne levels of TM.

Description of TM monitoring data 2003–2017	*N*	Median (ng m^{-3})	Range (ng m^{-3})
All shellfish samples	280	43	1–101 600
Crab monitoring	188	56	1–101 600
Prawn monitoring	84	17	1–5133
Scampi monitoring	8	394	230–482
Tasks/area measurements in 2003–2006 study of crab processors	*N*	Median (ng m^{-3})	Range (ng m^{-3})
'Blowing' including both manual and automated systems	18	2534	344–101 600
'Automated blowing' where specifically identifiable	7	2304	344–27 256
Boiling/cooking	14	<1	1–300
'Cracking claws'	5	80	1–1940
'Picking'	22	52	1–5244
'Slicing' using small electric circular saws	3	1760	500–4890
'Washing' shells and equipment	3	100	20–700
Packing of crab meat	6	15	1–62
'Raw or live side'—pre-processing	4	10	1–110
Static measurements outside of processing rooms, corridors, offices, etc.	9	1	1–38

295 ng m^{-3}. In 1 unit monitoring along an automated filleting line fed with gutted salmon, the higher values were nearer where the heads removed and suctioned away and the fish split in two removing the major bones. Later pin-boning or hand trimming fillets, and secondary processing activity of mixing salmon sauces to prepare ready meals generally gave lower values.

Discussion

Data from the SWORD surveillance scheme show an excess incidence of OA in the UK seafood processing industry during 1992–2017, with limited airborne monitoring data for the processing of prawn, crab, and salmon supporting that significant exposure to major seafood allergens can occur in this industry.

Land-based seafood processing employs approximately 20 000 workers, approximately 5% of those in the whole food and drink manufacturing sector. Historically, land-based seafood processing has been carried out in separate units from those processing other foodstuffs, possibly reflecting the potential for 'tainting', but also that seafood processing needed to be close to where it was landed. The separation of seafood from other food processing largely continues. As the importance of port landings relative to seafood imports has diminished, there has been a move of some seafood processing units from the dockside into larger units. Other structural changes to the sector have included increased automation, increased secondary processing activities, e.g. the production of ready meals and also finding economic uses for more of the significant amounts of the waste material. Considerable primary processing is also performed on-board fishing fleets, and some imported seafood may have already undergone some primary processing in an industry that has a significant international basis.

Seafish identifies that the whole UK sector is increasingly becoming integrated e.g. some units processing both farmed and sea fish/shellfish, and that units may change the focus of their activities. Thus, the numbers of workers identified as processing sea fish and shellfish as opposed to those processing salmon/freshwater fish is ill-defined. However, some units solely process specific types of seafood and some units, especially in Scotland, only process farmed salmon or trout. Some primary processing activities carried out on salmon and trout farms may not be counted within the land-based processing sector as described by Seafish.

We estimate the annual average incidence rate of OA in the UK seafood processing sector as 70/100 000 (95% CI 49–91) employees over the period 1992–2017. This is 24-fold higher than that calculated for 'all other industries' over the same period. The 'all other industries' figure is comparable, but slightly lower than the 4.2 (95% CI 3.7–4.5)/100 000 from a reporting scheme centred on the West Midlands geographical area over a similar period (Diar Bakerly *et al.*, 2008). These figures can also be compared with OA incidence rates calculated on SWORD data for all industries and food manufacture of 0.6/100 000 and 5.7/100 000, respectively, for the period 2008–2016 (www.hse.gov.uk/statistics/tables/thorr5.xlsx). The latter sector would include the seafood processing sector. Thus, the OA data in this paper suggest that there has been a significant risk of OA in the seafood processing industry, but give little idea whether this increased risk is historical or continues currently.

The calculated decreasing trend in OA incidence during 1992–2017 in the seafood processing sector was statistically significantly faster than that for 'all other industries'. However, the numerical means differences are marginal and the wide CIs in the seafood processing industry even encompasses no decreasing trend in OA. The relatively small dataset makes it impossible to investigate the trend by subdividing the time frame into shorter periods. Analysis of all OA data from SWORD suggests an annual decrease over the period 1999–2016 of −6.8% (95% CI −7.9, −5.7), although analysis of the relative risks by year shows an initial decline during 1999–2007 followed by a relatively flat trend during 2007–2016 (Carder *et al.*, 2017b); an increase in OA from 2014 has been also been suggested (Seed *et al.*, 2019) The apparent downward trend in estimated incident rates of OA has been discussed in terms of both artifactual causes and real changes (Carder *et al.*, 2017a,b). Therefore, caution needs to be exercised in interpreting the identified decreasing trend of OA in this paper.

Reports to SWORD include those asthma cases serious enough to be seen by a specialist chest physician, so it is likely these figures underestimate the true incidence of OA. In this paper, we have not analysed the incidence or prevalence of other, possibly less serious, allergic symptoms (respiratory, ocular, or dermal), although rhinitis may be reported to SWORD and dermal cases to the EPIDERM scheme. Similarly, we have no information on the implementation of health surveillance across the sector in the UK, which would be mandated under the Control of Substances Hazardous to Health (COSHH) regulations, and that should have influenced the identification of OA and other allergic symptoms.

A review (Jeebhay and Cartier, 2010) suggests that the causative agents of OA are more likely to be shellfish than fish, with prawns the predominant species. There can sometimes be ambiguity between terms such as prawns, shrimps, Dublin bay prawns, and scampi. It is interesting to speculate whether the causative burden of OA from seafood exposure reflects the amount of the specific species processed. Certainly, the amounts of prawns processed from combined imports and landings are in larger quantities (see Supplementary Table S2, available at *Annals of Work Exposures and Health* online data) than many other shellfish, albeit some prawn imports may have undergone some prior processing e.g. cooking, de-shelling. UK landings of crabs, scampi, and scallops are sizeable, but the latter two species are exported in high levels, including transportation to the continent without any UK processing. Prawn processing is also without the seasonality associated with UK-landed crabs. While the relative amounts of prawns processed may explain to some extent the predominance of prawns as the predominant causative shellfish species, it is unclear how the nature of work tasks involved in processing may contribute to the risk. It is also possible that some workers may have been prior sensitized to prawns, being a common UK foodstuff. It seems likely the risks reflect, in an inter-related way, the amount of each species processed, the nature of aerosols produced by specific processing techniques, and the amount of allergen(s) within each species.

Shellfish processing involves the removal or partial removal of the exoskeleton, either manually or by automation. For crabs this can involve the use of electric saws and systems to blow meat out of crab legs, our exposure data suggest that such processes may lead to high exposures. Prawn processing can involve thawing, de-shelling, cleaning, and cooking. Many of these processes have been automated to remain cost competitive. Automated prawn de-shelling systems are often based on extruding the meat from shells on rotating roller systems with removal of waste shells by water or air jets. Currently we have little idea of the extent and nature of automation in UK for shellfish processing and likely allergen levels produced during these tasks. Based on the very limited data within this paper, automation of air blowing crab legs has not been associated with lower airborne exposures. There is a need to establish whether current automation controls exposure, as well as affording productivity gains.

Salmon and/or trout are identified as the predominant OA causative fish species. Large amounts of salmon are processed, whether from the UK or imported, but in contrast the amount of trout farmed and processed in the UK is small (Supplementary Table S2, available at *Annals of Work Exposures and Health* online). While this study focussed on processing and attempted to exclude fish farming from the study, this distinction may not be easy where Scottish aquaculture is involved, also cases ascribed to trout may be due to salmon. Specific IgE measurements or skin prick tests are unavailable to help the attribution of causative species. It is not clear whether the strong association of salmon with OA reflects specific riskier activities in processing this species, that salmon allergens are particularly potent, or simply that some processors only handle salmon or trout. Automation in salmon processing has become increasingly available e.g. de-sliming, de-heading, gutting, splitting, and deboning, slicing of blocks of frozen smoked salmon, and filleting to a constant size. Automation has become more prevalent in larger units, but there remains a large element of manual work.

A small number of cases suggest a non-immunological causation, by exposure to irritants. Metabisulphite has been used as a preservative to prevent oxidation in shellfish, e.g. the appearance of unsightly black staining/spotting of prawns. This chemical has already been identified as a cause of occupational airways disease in two prawn processors (Steiner *et al.*, 2008).

A 1987 Seafish report (Mills, 1987) highlighted that 42% of units surveyed used high pressure sprayers for washing down as well as using yard brushes. The use of high pressure sprays on contaminated surfaces can be a potential source of aerosol generation. However, in the early 2000s HSE indicated that such washing activities in the sector may not be in line with the COSHH regulations. Certainly, more recently, larger and mixed processing plants often make use of specialist cleaning teams, operating outside of normal working hours and without employing high pressure water jetting techniques in order to meet food hygiene regulations. This early Seafish report also highlighted that some elements of the fish processing sector, particularly in the smaller port-based units, had standards well below that found in other areas of the food processing sector at that time. It is very likely the standards have improved.

Care needs to taken in comparing the exposure levels reported in this study with published data, due to methodological and standardization differences. Jeebhay and Cartier (2010) suggested airborne exposure levels as high as 1000, 6300, and 21 000 ng m^{-3} for processing scampi, prawns/shrimps, and snow crabs, respectively. The upper exposure values we report for scampi, prawns, and crabs are largely comparable with these figures. Jeebhay *et al.* (2001) also suggest levels up to 1600 ng m^{-3} for salmon processing and a 2012 study (Dahlman-Höglund *et al.*, 2012) in a Scandinavian salmon processing plant with three cases of OA, and using a very similar analytical methodology for salmon PARV showed comparable exposure levels. While currently there is a lack of a body of airborne monitoring data from UK salmon processing, we have identified exposures approaching 1000 ng m^{-3}. Our available airborne monitoring data suggest that high exposure levels to allergen can occur in the shellfish processing sector, as reported in non-UK studies, but it should not be over-interpreted. Firstly, only around half of our data is from a targeted survey, the remainder simply relies on commercial monitoring activity by occupational hygienists. It is interesting that only 329 measurements were undertaken during 2003–2017 in the shellfish processing sector, while in 2005–2017 HSE's laboratory has undertaken some 7500 airborne measurements to help control exposure in laboratory animal facilities (Mason and Willerton, 2017). There remains no well-established dose–response relationships for risk of allergic responses to fish or shellfish allergens, except for OA in snow crab processors (Gautrin *et al.*, 2010). Therefore, the emphasis must be on identifying high-risk activities and ensuring that appropriate control measures are in place to reduce exposure.

This study has highlighted a significant incidence of OA in this UK sector, largely immunological, and has identified some fish and shellfish species that appear to predominate as causative species. There are limited airborne monitoring data but they suggest that high exposures to allergens can occur in prawn, crab, and salmon processing. Limitations of this study include that the trend in the incident rate within the 25-year period cannot be defined and that other allergic symptoms have not been considered. Further work is warranted in determining the current incidence rate of OA in this sector in comparison with other asthmagen-exposed sectors, together with a better understanding of current work practices and associated levels of exposure to ensure that risk can be controlled as far as is practicable in this sector.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

Funding

This publication and the work it describes were in part funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

Conflict of interest

None of the authors declare any interest or potential conflict of interest related to this publication.

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