Sea-to-Plate:

The welfare journey of decapod crustaceans

Crustacean Compassion

CRUSTACEAN COMPASSION

Email: info@crustaceancompassion.org

Website: www.crustaceancompassion.org

Twitter: @crab_welfare

Contents

Contents

Executive summary

Welcome to the Crustacean Compassion Sea-to-Plate Welfare Report.

Each year in the UK over 420 million crabs, lobsters, nephrops (also known as langoustines) as well as prawns & shrimp are landed by UK vessels into UK ports. A further five billion prawns and other decapod crustaceans are also imported into the UK annually. An indicator of the financial value of this trade is the over 48 thousand tonnes of prawns, shrimps, nephrops and crabs sold by UK retailers alone each year, which has a corresponding retail sales value of over £670 million.

The rise and public interest in aquatic animal welfare and the progress made on decapod crustacean welfare science over recent years resulted in decapod crustaceans being recognised as sentient animals for the first time in UK legislation. Their inclusion in the Animal Welfare (Sentience) Act 2022 was celebrated and seen as a great step forward for both decapods and animal welfare in the UK and gave reason for optimism that the welfare compromises, detailed in this report, would be effectively addressed leading to the humane treatment these animals deserve.

The legal and scientific acknowledgement of their ability to feel pain and to suffer prompted many discussions about the welfare impact of current practices through the 'Sea to Plate' journey for decapods in the seafood industry. Unlike most other live animals in the food sector, decapods currently have little to no legal protection from inhumane practices during capture, handling, transport, storage and slaughter. Furthermore, there is widespread use of non-therapeutic mutilations – procedures which destroy, remove or damage the limbs or other body parts. Many of these industry practices result in unnecessary suffering as they were not designed with decapod welfare in mind. Although some informal guidance for the handling and slaughter of decapods does exist, the focus is on product quality rather than welfare.

Executive summary

This report provides a detailed review of the Sea to Plate journey experienced by decapods, from capture to eventual slaughter. Highlighting at each stage the welfare compromises experienced, relevant scientific information, and recommendations to ensure welfare and species-specific needs are met. Whilst in some areas scientific evidence is lacking, a commitment to the accepted precautionary principle is stressed.

It is anticipated that this report and associated extensive references will be a vital resource for industry leaders and legislators to work further on this issue resulting in more appropriate protection and humane treatment. The focus of this report has been the Sea to Plate journey for decapods in the UK but the recommendations, and science which underpins them, could be applied to settings globally.

We, at Crustacean Compassion, firmly believe that in following these recommendations hundreds of millions of animals will be protected from suffering, that populations of animals in a diverse and delicate ecosystem will be sustained, and that both industry and the British reputation for high animal welfare standards will be enshrined. Political will, industry engagement and public expectation are vital to push forward these changes and Crustacean Compassion will continue to support this process through its ongoing efforts.

Crustacean Compassion will continue to use a robust, evidence-based approach to campaign for the inclusion and enforcement of decapods in all UK animal welfare legislation, as well as highlighting the relevance of this issue within related subjects including food security, sustainability, human health and marine conservation. The development of legal and enforceable Codes of Practice for use in industry, alongside the inclusion (and enforcement) of decapods in all UK legislation relating to sentient animals – the Animal Welfare Act, The Welfare of Animals in Transport Order, the Animals at Time of Killing Regulation, and the Animals (Scientific Procedures) Act, is vital to address the suffering which is currently experienced on a vast scale in the UK and Crustacean Compassion will continue working alongside key stakeholders to achieve this.

We hope that you find this report enlightening and that it provides reasoned options to endorse and implement change – in policy, in procedure, and in everyday practice. The report represents a cumulation of a large body of work that we are both excited to bring and by the potential impact it may have on millions of currently ignored lives.

Let’s not waste this opportunity for real and lasting change, it is time to act.

Dr Ben Sturgeon
CEO
Crustacean Compassion

About

This report was authored by Crustacean Compassion and Dr Julia Wrathall.

Crustacean Compassion

Crustacean Compassion is a not-for-profit animal welfare organisation which campaigns for the legislative protection and humane treatment of decapod crustaceans such as lobsters, crabs, prawns and nephrops, based on the scientific evidence of their sentience. Crustacean Compassion does not campaign against the use of decapod crustaceans as food. Instead, it welcomes good practice in the food industry and believes that all decapod crustaceans should have their species-specific needs met. For more information visit www.crustaceancompassion.org

Julia Wrathall

Julia Wrathall is an independent animal welfare consultant with a background in applied welfare science and policy development across many species and areas of human-animal interaction, including farmed, companion and wild animals and those used in research and testing. She is currently a Non-Executive Director on the Animal Health and Welfare Board for England and a member of the UK governmental advisory body, the Animal Welfare Committee. She also serves on the Animal Welfare Research Network Stakeholders Advisory Board.

Julia worked for the RSPCA for many years both as Head of Farm Animals and as Chief Scientific Officer, leading the work of the Society's Science & Policy team. Her responsibilities included development of the RSPCA's farm animal welfare standards, the Assurewel on-farm welfare outcome assessment programme and the RSPCA's animal welfare policies across all species. Julia's work has also involved extensive advocacy, thought-leadership and partnership-building outreach with multiple stakeholders across many sectors on animal welfare science and its practical application to improve animals' lives. She has served, and continues to serve, on a number of committees in the animal welfare, farming and academic sectors in the UK and abroad.

Introduction: An overview of the journey from sea to plate

Every year billions of animals like crabs, lobsters, nephrops (langoustines), prawns and crayfish (decapod crustaceans) are captured and transported around the world by sea, air and land for commercial purposes [1]. In the UK alone, over 420 million decapod crustaceans are landed by UK vessels into UK ports [2]. Throughout the journey from sea to plate, they experience multiple stages – capture, storage, transport and eventual slaughter – each of which has their own set of stressors which result in low welfare, increased disease prevalence or mortality.

Some stressors are only present at specific parts of the supply chain, while others occur repeatedly from capture to slaughter/killing. For example, the capture method and hauling speed are factors that are only relevant during the capture stage. Similarly, starvation and dehydration primarily occur during transport as decapods are fasted prior to relocation. *Continued on page 11* →

Annual impact

The global scale of decapod crustaceans captured, transported and used commercially is vast.

Each year in the UK over

420 million

crabs, lobsters, nephrops (langoustines) and prawns/shrimp are landed by UK vessels into UK ports [1]

A further

5 billion

decapod crustaceans are also imported into the UK annually [2]. Many of these animals will suffer throughout their journey from sea to plate.

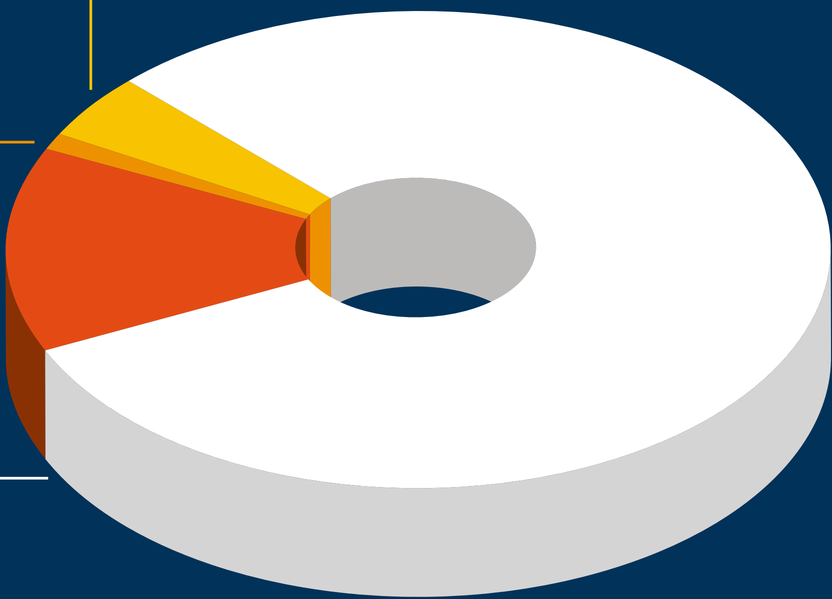
The 420 million animals are broken down by:

19.7 million
crabs

4.37 million
lobsters

58.67 million
prawns and shrimp

337.87 million
nephrops



[1] Crustacean Compassion (2020). Scale of impact report.

[2] Crustacean Compassion (2021). A scale of animal impact – prawn/shrimp imports.

Numerous other factors however, such as inappropriate environmental conditions (water quality, salinity, humidity, temperature), restricted movement and handling negatively impact the welfare of decapods at almost every stage of the sea to plate journey.

A note on sentience

In April 2022 decapod crustaceans were recognised as sentient in UK law following their inclusion in the Animal Welfare (Sentience) Act 2022 [3]. This decision was taken following an extensive review of the scientific evidence of their sentience by a team at the London School of Economics and Political Science (LSE) [4], commissioned by the UK government. This legal acknowledgement of their ability to feel pain and to suffer has prompted many discussions about the welfare impact of practices throughout the sea to plate journey for decapods in the UK seafood industry. This report outlines some of the most common practices through the sea to plate journey, and the stressors and welfare outcomes associated with these.

As recognised and legally protected sentient animals, it is implicit that at all stages of their lives, their welfare is paramount – both at sea and when being treated as food animals.

Capture and on-board holding

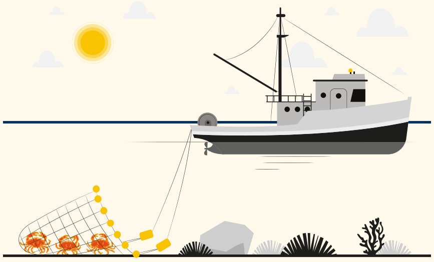
Decapod crustaceans destined for food production are either wild-caught or 'harvested' on farms. A variety of capture methods are used for this, depending on factors such as the species, scale and local traditions involved. Capture methods include the use of baited pots or traps, trawling, gill or drag nets, through draining ponds, or in small numbers the animals may be speared or caught by hand. The extent of welfare compromise experienced during capture is significantly affected by the method used and can include exposure to shifts in barometric pressure [5,6], salinity [7], temperature [8], physical trauma, injury and crushing [5,6,9,10], exhaustion [9–12] and death.

Once on deck, wild-caught decapod crustaceans are exposed to many more stressors such as air, light, temperature fluctuations and noise. They also experience handling as they are removed from pots and nets, sorted and moved to on-board holding facilities [13]. These in turn involve more welfare challenges such as inappropriate and/or fluctuating temperatures, physical disturbances, extended air exposure, or immersion in water with high ammonia levels and/or inappropriate salinity [13]. The animals are also closely confined together, often at high stocking densities and without the opportunity to hide, resulting in the restriction of their natural behaviours and potentially antagonist interactions with others of the same or different species [13]. To reduce injuries from fighting and for handler safety, crabs and lobsters are also frequently subjected to claw nicking or banding.

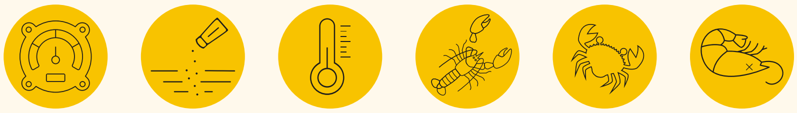
Research shows that as a result of these experiences, lobsters [14,15], shrimps [16], crabs [8] and nephrops [17] suffer physiological disturbances such as high haemolymph lactate and glucose [17], which can last several days in post capture [14]. They may also suffer from wounds and infections, limb loss (through autotomy), toxicity and salinity stress, temperature stress, hypoxia and mortality, either on board or after transfer to recovery holding tanks on land [13,18].

Some noted risk factors for loss of vigour at capture include tossing (rather than placing) the animals from traps into temporary holding units, exposure to rain (likely to be due to sensitivity to freshwater), sunlight, rough weather and warm weather while on-board the boats [19]. Seasonal differences also affect animal survival during and after *Continued on page 14 →*

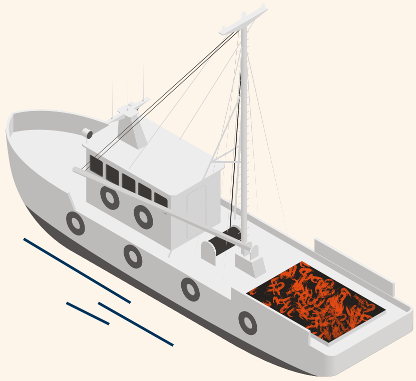
Capture Overview



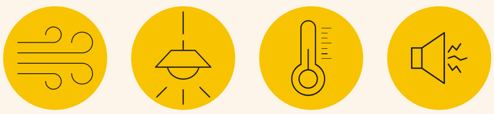
The extent of welfare compromise experienced during capture is significantly affected by the method used but can include exposure to:



Shifts in barometric pressure | Fluctuating or inappropriate salinity | Fluctuating or inappropriate temperature | Physical trauma | Injury and crushing | Exhaustion and death

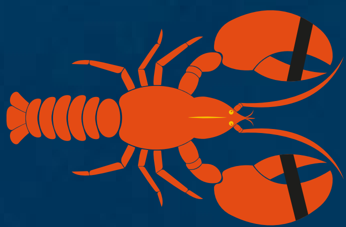


Once on deck, wild-caught decapod crustaceans are exposed to many more stressors such as:

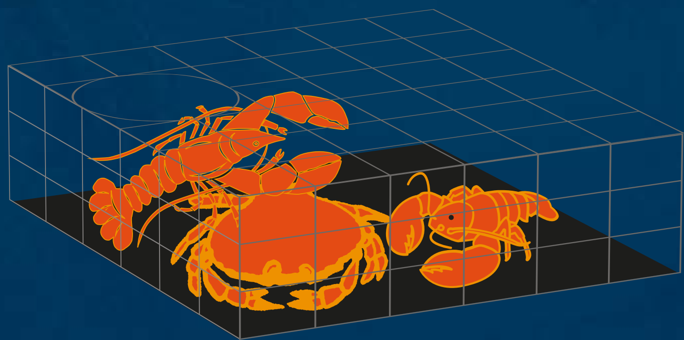


Air | Light | Temperature fluctuations | Noise

They also experience handling as they are removed from pots and nets, sorted and moved to on-board holding facilities. These in turn involve more welfare challenges such as inappropriate and/or fluctuating temperatures, physical disturbances, extended air exposure, or immersion in water with high ammonia levels and/or inappropriate salinity.



To reduce injuries from fighting and for handler safety, crabs and lobsters are also frequently subjected to claw nicking or banding.



The animals are also closely confined together, often at high stocking densities and without the opportunity to hide, resulting in the restriction of their natural behaviours and potentially antagonist interactions with others of the same or different species.

Research shows that as a result of these experiences, lobsters, shrimps, crabs and nephrops suffer physiological disturbances such as high haemolymph lactate and glucose, which can last several days in post capture.

They may also suffer from:

Wounds and infections | Limb loss (through autotomy) | Toxicity and salinity stress | Temperature stress | Hypoxia | Mortality

either on board or after transfer to recovery holding tanks on land.

capture, highlighting the immediate effect of temperature shock due to the difference in temperature between the sea bottom and the deck [8]. Better survival rates are seen in decapods caught and locally transported when environmental conditions are favourable, and when they are not moulting [18].

Holding and storage

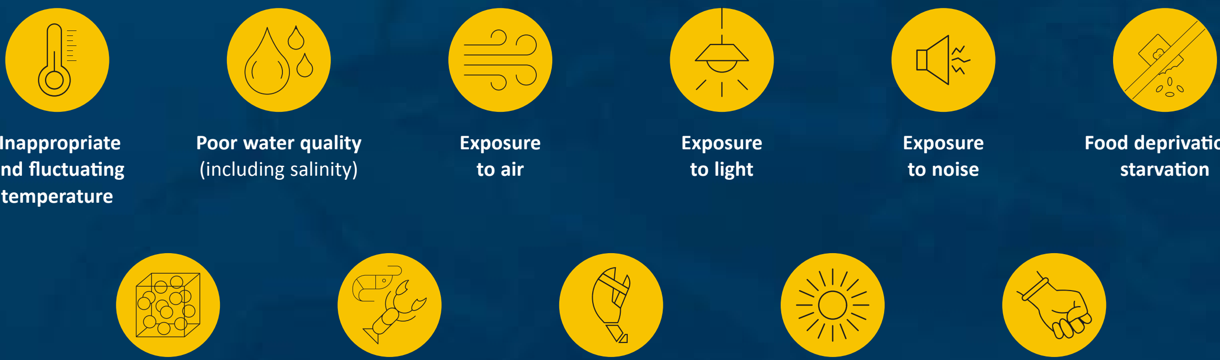
Huge numbers of decapod crustaceans are subjected to some form of holding or storage at various stages from the time they are captured in the wild or 'harvested' on farms until they are killed. This includes during pre-and post-transport periods, in transit, prior to killing/processing, and while on live display in retail outlets, restaurants and live markets [20]. The duration of storage can vary, sometimes being for several months [21,22]. The conditions – and associated welfare challenges – are hugely variable.

Depending on the species and duration of storage, the animals may be held in water tanks with or without water recirculation, in air at various levels of humidity/moisture [23], and sometimes directly on ice [20]. As such, the welfare risks include inappropriate and fluctuating temperature, poor water quality (including salinity) [20], exposure to air, light and noise, food deprivation/starvation [24], overcrowding [25], mixing with conspecifics and other species [20], behavioural restrictions (including through claw banding), lack of shelter and also handling, including when being 'graded' for size and quality [25]. As a result, the animals can suffer significant stress, physiological and immunological disturbances [24], hunger, muscle depletion [21], injury, increased disease prevalence and mortality [25]. Certain practices, such as the displaying of live decapod crustaceans in retailer outlets and restaurants, are not only rife with welfare and ethical concerns [20] but are also not a necessary part of the logistics of achieving the sea to plate journey. The welfare concerns are further exacerbated by uncertainties about the competency and methodology surrounding the subsequent killing of the animals in such outlets.

Holding overview

Depending on the species and duration of storage, the animals may be held in water tanks with or without water recirculation, in air at various levels of humidity/moisture [23], and sometimes directly on ice.

As such, the welfare risks include:



- **Inappropriate and fluctuating temperature**
- **Poor water quality** (including salinity)
- **Exposure to air**
- **Exposure to light**
- **Exposure to noise**
- **Food deprivation/ starvation**
- **Overcrowding**
- **Mixing with conspecifics and other species**
- **Behavioural restrictions** (including through claw banding)
- **Lack of shelter**
- **Handling** (including when being 'graded' for size and quality)

As a result, the animals can suffer:

- **Significant stress**
- **Physiological and immunological disturbances**
- **Hunger**
- **Muscle depletion**
- **Injury**
- **Morbidity**
- **Mortality**

Transport

Many millions of live decapod crustaceans undergo transportation for commercial purposes every year [26–28]. During transport, they are subjected to a broad range of conditions on journeys of differing length and duration, some lasting several days [26,29]. Every journey an animal involuntarily undertakes is stressful, so robust justification for each journey and the minimisation of the stress are imperative [30].

Common transport practices expose decapod crustaceans to multiple stressors [28], including inappropriate and/or fluctuating temperatures and other environmental conditions (e.g. water quality), unsuitable packaging/containment, overcrowding, stacking, air exposure, vibration, noise, light and handling. Confinement in close proximity to others of the same or sometimes different species also poses welfare challenges [28]. The loading and the unloading processes also involve exposure to stressors such as temperature change and air and sun exposure [25,31,32]. As a result, the animals experience many physical, physiological, immunological, and behavioural disturbances [28]. This inevitably causes suffering and results in sometimes extremely high levels of mortality both in transit [26,29,33], and during recovery at the destination [25,26,32], depending on the conditions, duration of travel and also the resilience/adaptability of the species [25].

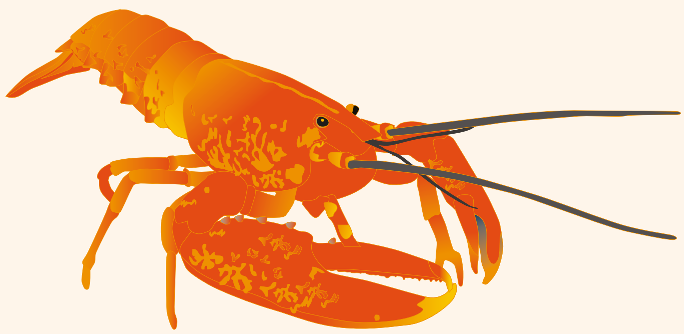
The effects of this stress on live decapod crustaceans tend to be cumulative, being reflected in increased rates of mortality at holding facilities (e.g. as high as 60% [34]). However, survival is an inadequate indicator of wellbeing during/after transport, since even in species considered to have a relatively higher tolerance of stress (e.g. freshwater crayfish) [28], much suffering may be experienced in transit without death occurring. The impact on surviving animals can also be long lasting post transport [26,35]. Anaesthetics such as AQUI-S® have been used as a means of reducing impact of transport conditions on decapod crustaceans, but these have very mixed results depending on conditions, temperature, stocking density and species [35–37]. Their use should be considered illegal under the terms of the Veterinary Surgeon Act [38], and takes no account of drug withdrawal times, food safety, nor of environmental damage to released water.

Transport overview

Decapod crustaceans are transported in conditions that vary greatly, including various designs of tanks, viviers, and packaging material or containers. These journeys also differ in length and duration, some lasting several days.

Common transport practices expose decapod crustaceans to multiple stressors, including:

Confinement in close proximity to others of the same or sometimes different species also poses welfare challenges. The loading and the unloading processes also involve exposure to stressors such as temperature change and air and sun exposure.



As a result, the animals experience many physical, physiological, immunological, and behavioural disturbances. This inevitably causes suffering and results in sometimes extremely high levels of mortality both in transit, and during recovery at the destination, depending on the conditions, duration of travel and also the resilience/adaptability of the species.

Stunning and slaughter

In order to kill a crab or lobster humanely they must first be stunned effectively, followed by mechanical killing, before they are cooked. It is not, therefore, possible to humanely slaughter animals like crabs and lobsters at home. The steps required for humane slaughter must be carried out by a trained professional.

> Decapod crustaceans should only be stunned using methods that result in instantaneous (within one second) insensibility to pain and distress or where insensibility is induced without causing pain and distress. This insensible state must be maintained until death occurs. Slaughter must then also occur instantaneously or the insensible state must be maintained until death occurs. Killing should always be carried out by trained and competent practitioners, and never by amateur consumers.

Humane stunning

Currently, electrical stunning is the best option available for rendering decapods insensible. This must be done immediately before a swift and effective killing method (there is currently insufficient evidence to support electrical killing as an effective humane killing method). Evidence indicates that electrical stunning can deliver a quick, effective and humane stun to decapod crustaceans including crabs, lobsters, crayfish and shrimps, when appropriate electrical parameters are applied for the species [39–42]. Electrical stunning should only ever be done with approved, specialist equipment. There are various pieces of equipment available at a range of prices.

Humane slaughter

Effective stunning, which is guaranteed to last until the animal is dead must take place prior to slaughter, regardless of the slaughter method used. Currently, electrical stunning followed by mechanical killing by trained professionals is the most humane method of slaughter.

Stunning & Slaughter

Humane

Decapod crustaceans should be stunned using methods that result in instantaneous* insensibility to pain and distress. This insensible state must be maintained until death occurs via mechanical killing.

Electrical stunning immediately followed by

Mechanical killing (spiking or splitting)

*within one second

Humane with caveats

The following may result in humane slaughter if further parameters are fulfilled first. However, more research is needed.

- **Electrical killing**
- **Spiking or splitting**
- **High-pressure processing**
- **Boiling**

Inhumane

The following are not appropriate either alone or in combination.

- **Dismemberment**
- **Fresh water 'drowning'**
- **High salt solution**
- **Dry/air chilling**
- **Wet/ice chilling**
- **CO_2 gassing**
- **Chemical anaesthetic**

Mechanical killing comprises two methods: ‘spiking’ of crabs and ‘splitting’ of lobsters and similarly shaped species. When performed by a trained and competent practitioner these methods effectively destroy the nerve centres (ganglia), resulting in relatively swift death. Due to the skill required for an accurate and rapid death, those performing this method must be adequately trained. Neither spiking nor splitting are suitable for killing large numbers at one time. Operator fatigue could lead to reduced accuracy, and improper performance of spiking and splitting could lead to severe suffering.

The boiling of effectively stunned decapods as a method of slaughter can be humane, as long as the stun lasts throughout the entire slaughter process. However boiling live, conscious decapods is inhumane and should never be attempted.

Inhumane methods of stunning and slaughter

Many of the current methods used to kill decapods for consumption are actually ineffective and inhumane. **Based on current scientific evidence, the following methods are considered inhumane and should not be used on decapod crustaceans:**

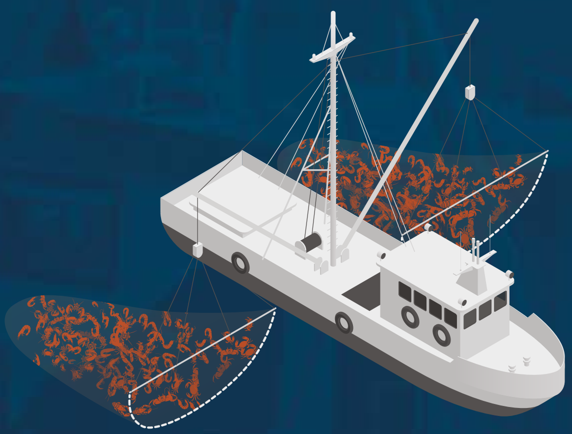
- Live, conscious boiling
- Chilling in the fridge, freezer or in an ice slurry
- Dismemberment of live animals
- Freshwater drowning
- Electrical killing
- High pressure processing
- High salt solution
- CO_2 gassing
- Chemical anaesthetics

> The various welfare challenges posed by current practices through the sea to plate journey, along with recommendations for change, are outlined in detail in the issue-specific sections.

Overall recommendations

Capture

Capture and post-capture practices must be adapted, on a species-specific basis, to reduce to a minimum the impact on the welfare of decapod crustaceans. This includes both the target animals and those unintentionally affected during the processes.



Holding and storage

In order to reduce the suffering experienced by decapod crustaceans during holding/storage, the conditions must be optimised to meet species-specific needs, and the duration, frequency and the duration and frequency of periods of storage of periods of storage, must be minimised.

Transport

The occurrence, frequency and duration of transportation of live decapod crustaceans must be minimised. Travelling conditions must be adapted to the species to optimise welfare, and approaches that replace live transport with a carcass-only trade developed and implemented.

Stunning and slaughter

Decapod crustaceans should only be stunned using methods that result in instantaneous* insensibility to pain and distress or where insensibility is induced without causing pain and distress. This insensible state should be maintained until death occurs. In addition, decapod crustaceans should only be slaughtered/killed using methods that result in either instantaneous* death or instantaneous* insensibility to pain and distress until death occurs.

within one second

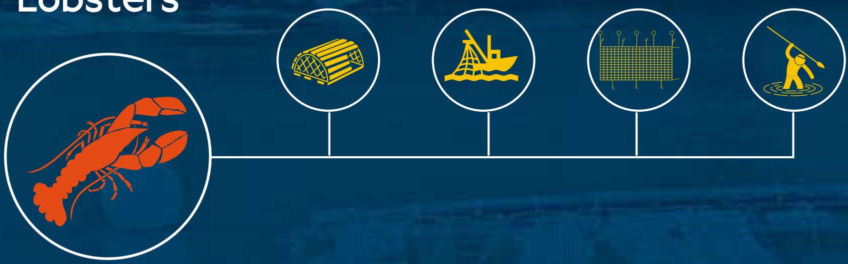
Focus on capture

Method of capture

The capture method of decapods varies with species, scale and local traditions and it significantly affects welfare. Lobsters and crabs are usually caught in baited pots or traps which are designed to enable the animals to enter but not leave [43], trapping them until the pots are hauled up to the boats. Some lobsters may be trawled in nets, which introduces additional welfare challenges as well as the risk of bycatch of non-target decapod crustaceans and other species. Lobsters may also be captured by entangling or gill nets, or in small numbers, may be speared or caught by hand [44,45]. Nephrops are mostly caught by net trawling and only more rarely in pots [46]. On most shrimp farms, the shrimps are harvested via drag nets or through draining ponds, for example through sluice gates [47] whilst farmed crayfish are caught in surface baited traps [48].

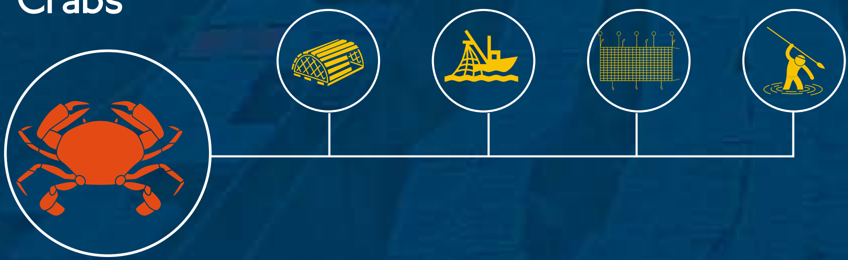
Focus on capture

Lobsters



Lobsters are usually caught in baited pots or traps [43] but some may instead be trawled in nets. Lobsters may also be captured by entangling or gill nets, or in small numbers, may be speared or caught by hand [44,45].

Crabs



Crabs are usually caught in baited pots or traps [43] but some may instead be trawled in nets. Crabs may also be captured by entangling or gill nets, or in small numbers, may be speared or caught by hand [44,45].

Nephrops

Nephrops are most commonly caught using net trawlers, although creel pots are used occasionally [46].

Shrimps / prawns

On most shrimp farms, the shrimps are harvested via drag nets, trawling, or through draining ponds, for example through sluice gates [47].

Crayfish

Farmed crayfish are caught in surface baited traps [48].

Trawling and trapping

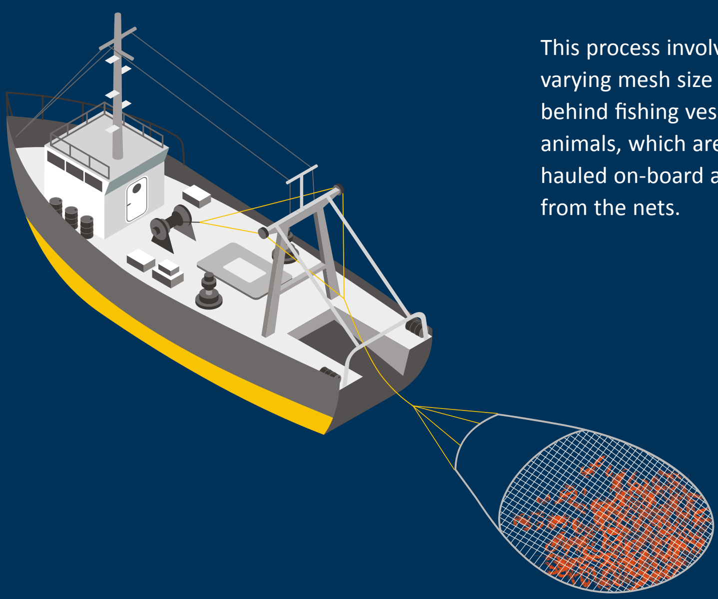
Capture by trawling and subsequent on-board practices cause immense stress, physical damage and exhaustion to decapod crustacean species [5,8,9,50,51], generally having greater negative impact than other methods such as pot/trap capture. In addition, the ability to adapt the size, shape, mesh size, and the design of entries and exits of pots and traps makes them highly species-specific, thereby reducing the volume and diversity of bycatch compared to mobile gear such as trawls or dredges [52]. Nevertheless, their use is associated with a number of negative impacts on the captured animals and the environment.

Trawling

Capture by trawling and subsequent on-board practices cause immense stress, physical damage and exhaustion to decapod crustacean species such as nephrops [9,50], shrimps [5], crabs [8] and lobsters [51], generally having greater negative impact than other methods such as pot/trap capture. The process involves nets of varying mesh size being pulled behind fishing vessels to trap the target species, which are subsequently hauled on-board and released from the nets.

The high impact on the animals results from almost simultaneously occurring multiple stressors. These include exertions – for example, due to tail flipping behaviours in some

Trawling



This process involves nets of varying mesh size being pulled behind fishing vessels to trap the animals, which are subsequently hauled on-board and released from the nets.

species as they try to escape the net [11,12], abrasions from contact with other animals and objects in the net [5,6], oxygen deprivation due to air exposure during on-board sorting [12,50,55], temperature variations [8], and changes in salinity [7] and pressure due to hauling from depth [5,6,9,56,57]. Trawl capture and emersion of nephrops can result in lesions and necrosis of abdominal muscles [57], whilst the capture, capture method and emersion of nephrops collectively evoke physiological and immunological responses that have implications for their ability to survive.

Trawling and subsequent emersion combined elicit progressive and significant increases in levels of haemolymph L-lactate, glucose and total ammonia which, coupled with the evidence of overt activity, suggest that trawl-captured nephrops are less likely to survive than those caught by creel (pot) fishing [50]. In addition, whilst trawling yields larger landings of nephrops, it has been shown to provide smaller individuals in poorer condition than pot/creel fisheries (thereby obtaining lower unit prices) [58]. Some research indicates that whilst on deck, many nephrops (55%) fail to show strong signs of life with some (16%) showing no life signs at all [58]. Longer trawls (2.5 – 4 hours) correspond to increased damage in “hard” (intermoult) nephrops compared with shorter (up to 60 minutes) trawls [6,9]. This may, in part, be explained by the fact that longer trawls yield higher proportions of smaller animals, and these are more likely to be damaged by the trawl [6]. However, progressive increases in haemolymph lactate and reductions in energy levels are also seen in trawled nephrops as trawl time rises, with even a short trawl duration (15 minutes) leading to higher levels than those seen in creel caught animals [9]. A greater proportion of nephrops are also found to be heavily damaged following longer trawls in spring [59].

Increasing trawl tow time also leads to a rise in mortality in shrimp [18] , further indication of the negative impact on welfare of extended trawl duration. In addition, trawl fishing results in greater impact on the environment (and hence on the wellbeing of aquatic animals) than other capture methods such as pots/traps, including levels, duration and area of seabed disturbance. Whilst levels of bycatch (including non-target decapod crustaceans) are also greater when trawling is undertaken [49]. There is some evidence that changing the size and shape of trawl netting affects the condition and survival rates of non-target sizes of decapod crustaceans or other species that manage to escape from the nets during the trawl [60], indicating that adjustments could reduce the negative impact on bycatch.

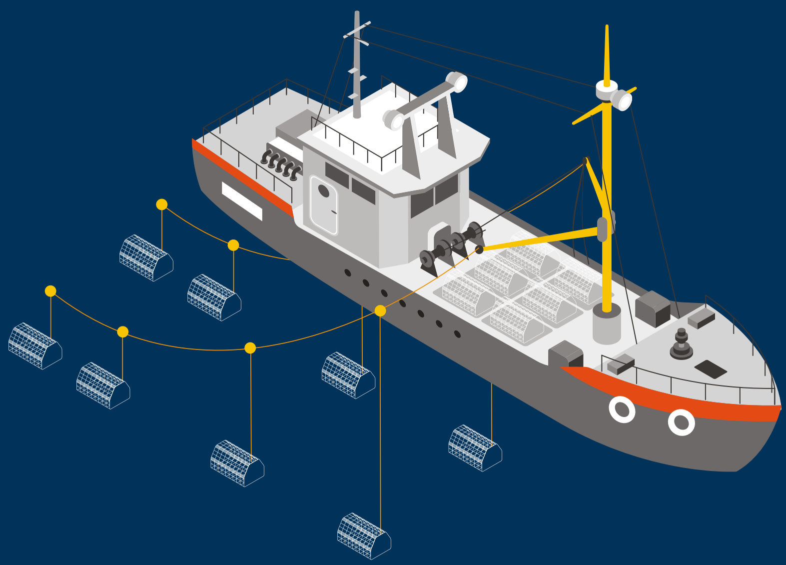
In summary, a compelling body of evidence indicates that use of trawling as a capture method for decapod crustaceans has very significant and wide-ranging negative impacts on both their short- and long-term welfare and survival, as well as affecting non-target aquatic animals. Some of the challenges posed to the animals could be reduced to some extent through adapting equipment, fishing and handling practices during and immediately following capture. Crustacean Compassion therefore recommends that available information on how to reduce impact should be applied in practice at each stage of capture and on-board treatment, an approach likely to improve the welfare and survivability of target and bycatch decapod crustaceans and as a consequence, to bring associated commercial benefits.

Trapping

Baited pots, traps and creels are commonly used types of fishing gear for capturing crabs, lobsters, shrimps and crayfish [53]. They are designed to enable the target species to enter but not to leave the catching chamber, trapping them until the pots are hauled up to the boats. Although some smaller traps are usually hauled by hand, hydraulic hauling devices are increasingly used to haul larger traps and pots, especially from deep waters [54].

Trapping

Baited pots, traps and creels are commonly used types of fishing gear for capturing crabs, lobsters, shrimps and crayfish [53]. They are designed to enable the target species to enter but not to leave the catching chamber, trapping them until the pots are hauled up to the boats. Although some smaller traps are usually hauled by hand, hydraulic hauling devices are increasingly used to haul larger traps and pots, especially from deep waters [54].



The ability to adapt the size, shape, mesh size, and the design of entries and exits, of pots and traps renders them generally highly species-specific, thereby reducing the volume and diversity of bycatch compared to mobile gear such as trawls or dredges [52]. Nevertheless, their use is associated with a number of negative impacts on the captured decapod crustaceans. Pot-trapped animals experience salinity [7], temperature [8] and barometric [5,6,9,56,57] changes as the pots are hauled on-board, often from significant depths of up to 200m [14]. This is followed by exposure to often extended periods (sometimes up to 24 hours) of emersion [50,55,61,62] once landed on deck and placed in holding containers. Some research indicates a significant interaction between hauling depth and storage methodology over time for non-surviving lobsters [14], whilst greater depths and faster hauling rates are also associated with higher rises in lactate levels in this species [14]. Exposure to wind chill/temperature fluctuations [63], light and the risk of physical trauma during removal from the pots [23] and other post-capture handling [52] will also occur. However, overall, use of pots/traps to capture decapod crustaceans tends to result in less serious welfare impact. For example, despite smaller landings than obtained through trawling, creel fishing of nephrops has been shown to provide individuals of larger size and in better condition, with a higher proportion (70% of creel caught vs 45% of trawled) showing strong life signs when on deck [58]. Similarly, both the evidence of overt activity and measured haemolymph parameters suggest that creel fishing yields nephrops that are more likely to survive post-harvest treatments than those that are trawled [50]. Pot design also influences welfare during capture, with hoop pots being associated with higher wounding of crabs than other designs [64].

Although in general, pots, traps and creels are less damaging to the environment than trawling, the exact design [64]and materials used (such as mesh size) [65] determine the level of risk of capture and retention of non-target sizes and species. Pots and traps can also cause serious problems if lost or discarded [66–68]. Loss of pots can be a common occurrence in some fisheries [69] and the lost gear may then continue to capture aquatic animals indiscriminately. This phenomenon, where decapod crustaceans are trapped in derelict pots and unable to escape, is known as ‘ghost-fishing’ and can lead to the slow death through starvation of large numbers of animals such as lobsters [67,69] and crabs [67,68]. The carcases in turn attract more animals into the pots, leading

to further mortality. Figures from some regions of the world suggest that hundreds of thousands of decapod crustaceans can die in ghost traps annually in a single fishery [46,69] with each lost pot responsible for multiple deaths [67]. The number of animals caught in a trap varies hugely with trap design and with species interactions, but they are responsible for huge losses from decapod crustacean populations [70]. Pot losses could be reduced or prevented through changes in current practices [66] and calculations suggest that it would be cost effective to retrieve them [71]. Moreover, the levels of fatal ghost fishing when pots are lost could be reduced through adjusting the design to enable escape, for example by incorporating a 'rot out' panel [54], larger mesh sizes or escape vents [64].

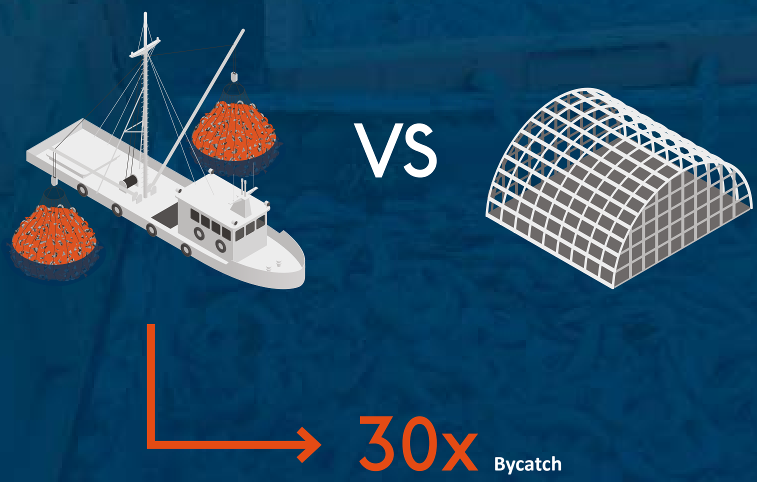
Overall, multiple factors influence the welfare and survival of pot-caught decapod crustaceans. Ensuring species-appropriate practices that minimise negative impact on welfare during all these procedures is essential at each stage. This includes optimising design of pots/traps to reduce injury, minimising hauling depth and rate, and applying considerate handling and treatment during and immediately after removal from the traps on deck. Changes to current practices and pot design to reduce the risk of pot loss and of associated deaths through 'ghost fishing', together with systematic retrieval of missing pots, should also be undertaken.

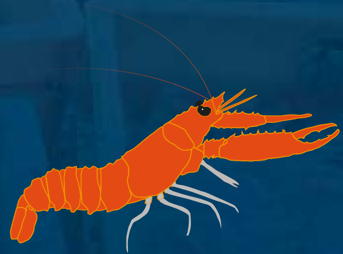
Bycatch animals

Decapod crustacean fishing often results in the unintentional capture of other animals as well as the target species. These may be non-target species or individuals of the target species who are unsuitable to be caught such as berried females [49,72,73].

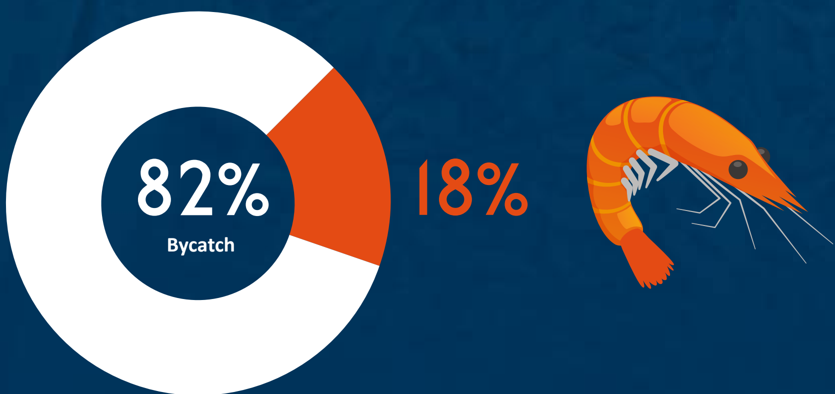
The amount of bycatch varies with method, location and design of equipment. Generally, levels of bycatch are greater when trawling is undertaken compared to trapping methods. The benefit of using traps rather than trawling is that they can be highly species specific, due to adaptations in size, shape, mesh size, the design of entries and exits and the provision of escape gaps for undersized animals [53,65]. The volume and diversity of bycatch can, therefore, usually be reduced.

Bycatch animals





One study found around thirty times more fish and undersized nephrops being killed in a nephrops trawl fishery compared with a creel fishery (i.e. respectively 4.5kg of bycatch vs 0.15kg of bycatch per kg of target animals caught) [49].



Some reports suggest the highest rates of incidental catch of non-target species are associated with shrimp trawling [72]. Analysis of such trawls in some locations has found over 150 different taxa in a single trawl, with the target shrimp species accounting for only 18% of the total, and other invertebrates (including decapod crustaceans such as crabs) and finfish species making up the rest [74].

Bycatch animals undergo the same experiences during capture, hauling and landing on deck as the target species, meaning they will suffer similar welfare impacts, affecting their ability to thrive and even survive if returned to the sea [60].

An assessment of the short-term mortality and stress incurred by juvenile bycatch prawns discarded after trawling suggests around 35% die within 72 hours after being caught. Just over half the deaths are due to the sorting and separation from the retained catch in air (as per normal commercial procedures) prior to discarding, with the remaining deaths being directly associated with trawling method [75]. Mortalities could therefore be substantially reduced if the processes associated with bycatch, landing, release and sorting were reviewed and improvements made, such as sorting being undertaken in water-filled compartments instead of in air.

A global estimate of only 35% survival rate has been calculated for nephrops released back into the ocean following capture by trawling and on-board landing, with several factors potentially affecting this figure including duration of the tow, season (with increased mortality in warmer months), and biological characteristics (e.g. size, sex) [76].

Data from a prawn trawl fishery has shown that over half (52%) the bycatch is made up of crustaceans, 15% of which died within eight hours of trawling and sorting [73]. Even when they survive, the capture, handling and release of by-catch can lead to issues such as reduced growth [77], impaired reproduction and damage to appendages [78].

Undersized lobsters are often left exposed to air on deck prior to discard and the resulting physiological impact diminishes their response time and ability to escape, leaving them vulnerable to predation when returned to the sea [79]. Some bycatch decapod crustaceans escape from trawl nets before being landed on deck. The impact on these animals varies considerably [60] depending on the degree of exposure to particular stressors during the capture and escape process. Factors known to influence survival include particular conditions associated with the fishing grounds (e.g. water temperature and catch composition [80]), as well as operational factors (e.g. type and mode of use of gear [80–82]). Other studies [83–85] have highlighted the potential of changes in mesh configuration to reduce bycatch by enabling escape of non-target animals. However, the adoption of any such change is only effective if escapees survive. Studies indicating mean survival rates of nephrop escapees of 70% for 45mm diamond mesh codends escapees [86], and over 80% and 85% for individuals escaping from 70 to 100mm diamond mesh codends and 60mm square mesh ones, respectively [87], suggest that changing the type and mesh size of nets could be beneficial.

There is a wealth of evidence indicating that sometimes high levels of bycatch can be associated with decapod crustacean fishing, including undersized individuals of the target species and other non-target species of decapod crustacean. Even when returned to the sea alive, many unintentionally caught animals suffer increased disease prevalence and mortality as a result of the stressors experienced during the catching and sorting processes. Crustacean Compassion wants to see changes to fishing practices and equipment, including the design and materials used for nets and pots, to facilitate a reduction in the level of bycatch. Refinement – and reduced duration – of on-board handling and sorting practices should also be undertaken to help improve the ability of discarded bycatch animals to survive and thrive on return to the sea

Post-capture handling

After capture in pots/traps or nets and hauling on board, those decapod crustaceans that remain alive on arrival on deck are exposed to multiple experiences that can result in stress, fear, physiological and immunological disturbances, trauma/injury, increased disease prevalence and mortality [8,14,23,31,55,57,88,89]. The stressors include various handling practices during removal from pots/traps, release from nets, sorting and placement into on-board storage, with the risk of trauma during this time heightened in some species such as lobsters as they begin to tail-flap vigorously as they leave the water and during sizing/ handling on the boat [90]. Also, the tossing – rather than placing – of animals into temporary holding units on board after removal from traps is a risk factor for subsequent loss of vigour in lobsters [19]. These outcomes indicate the importance of ensuring minimal and careful handling of all decapod crustaceans, both immediately post capture and at all stages.

As well as the physical disturbances, the handling processes involve the additional challenges of exposure to light, noise and to fluctuating/extreme temperatures [8,63,91,92].

Reports indicate that even short periods (e.g. 5 minutes) of exposure to windchill contribute to mortality rates, limb loss, and decreased activity in crabs [63,91]. The often lengthy periods of emersion experienced during the on-board handling [31,51,55,89,93] may extend to several hours and lead to serious and sometimes long lasting negative effects. Investigations of causes of mortality in postharvest lobsters suggest that those that became moribund during storage (‘rejects’) often have bacterial infections most likely resulting from physical handling, wounding and exposure to environmental extremes during or after capture [13]. Similarly, trawl capture and emersion of nephrops can result in lesions and necrosis of abdominal muscles [57]. The combination of temperature shock and air exposure also has significant influence on the ultimate stress of trawled crabs, even more so than the other effects of fishing [8]. Other environmental elements can also impact negatively on certain species, with exposure to rain on board boats being a risk factor for post-capture loss of vigour in lobsters, likely to be due to their intolerance to fresh water [19]. The level and frequency of training of on-board staff may impact on the wellbeing of decapod crustaceans too. One study indicates a three-fold increase in the risk of loss of vigour in lobsters at the processing plant when landed by captains with more than 20 years' experience, possibly indicating the importance of refresher training rather than relying on long experience [31].

In summary, the many stressors to which decapod crustaceans are subjected immediately following capture at sea lead to multiple welfare impacts both at the time and in the longer term. The available evidence-based, species-specific information, indicating which practices could be modified and refined in order to reduce the level of negative impact, needs to be reviewed and implemented in practice at each stage post-capture. Overall, handling processes should be undertaken with care and the frequency and duration minimised. In addition, animals should be protected from exposure to inappropriate environmental parameters during handling, sorting and transfer to holding containers. Refresher training of crew to ensure transfer and implementation of the latest knowledge in this area could also be beneficial.

On-board holding and storage

Methods of on-board storage of decapod crustaceans vary considerably in nature and in their impact on welfare. In some cases, the animals are stored in containers in air, either individually or together. The risk of injurious aggressive interactions between individuals of some species (such as crabs and lobsters) due to their forced close proximity is addressed by immobilising claws through banding or nicking (see: *Focus on mutilations and claw immobilisation* section for details). Some species such as nephrops may be held vertically in individual 'racks' though research suggests they should be allowed to recover from the challenges of trawl capture (heightened in warm temperatures) by holding them for several hours in on-board seawater tanks [56]. Studies indicate that lobsters should be both carefully handled and provided with a recovery period in recirculating seawater prior to land transport, especially those previously hauled from great depths and at higher speeds [14]. Similarly, the lesions and necrosis of abdominal muscles that can occur as a result of trawl capture and emersion of nephrops can be mitigated by submersion in on-board seawater tanks post capture [57]. Water quality parameters, including oxygen levels, in on-board tanks have significant influence on welfare [94]. Some crabs are kept in baskets and exposed to air for several hours after capture until their arrival at the factory, triggering oxidative stress. There are species-specific differences in tolerance to emersion on board, with some (e.g. Blue Lobsters) reportedly able to at least survive for several days [95] though without assessment of the associated nature and level of suffering over this period. One study assessed the critical time of air exposure as being around six hours after which crabs are unable to induce the synthesis of antioxidant enzymes or proteins, a factor that should be taken into account to minimize the stress generated by the commercial capture process [62]. Keeping the captured animals at low temperatures can make them both easier to handle and reduce handling stress [96]. For example, storing crabs on board at low temperatures is advised to reduce physiological stress and improve subsequent survival [97], whilst the main principles recommended during post-harvest handling of crayfish are to keep physical disturbances to the minimum and to provide cool and moist environments for the animals [23].

Overall, it is clear that the nature of the various on-board holding conditions in which decapod crustaceans that remain alive post capture are stored, can have a highly significant impact on many welfare parameters and on the animals' ability to survive longer term during subsequent transport and storage. Species-specific information on appropriate holding conditions, that take account of each species' physical, physiological and behavioural needs, should be understood and applied in practice.

See also:

Section 5: Focus on mutilations and claw immobilisation

- Declawing
- Claw nicking
- Claw banding
- Eyestalk ablation

Section 8: Common welfare issues throughout the sea to plate journey

- Air exposure
- Light exposure and lack of shelter
- Temperature fluctuations
- Extremes and Inappropriate water quality

Focus on mutilations and claw immobilisation

Mutilation is a term used to describe a procedure which destroys, removes or irreparably damages the limbs or other body parts of animals. It is often carried out to adapt an animal's body to fit the environment, and quite often for economic gain. These painful procedures are usually carried out without any anaesthetic or pain relief. In decapod crustaceans, mutilations such as eyestalk ablation, declawing and claw nicking are common practice.

Declawing

Declawing is the manual removal of one or both claws from a decapod crustacean, most commonly crabs. It is carried out both in fisheries and at sea. It has been a common misconception that declawing is not a painful practice, since crabs can naturally detach their own claws in response to stress or danger (natural autotomy). However, evidence shows this is not the case when the claws are forcibly removed e.g. by a human.

Manual removal of the claws, as opposed to natural autotomy, induces physiological stress responses (such as elevated lactate, glucose and muscular glycogen mobilisation [98,99]), impairment of feeding [100,101] and poor survival outcomes [98,101,102] indicative of seriously impaired welfare. Manually declawed crabs also show behaviours indicating an awareness of the resulting wounds, as they touch the wounded area or shield it with their remaining legs [103]. This is not seen when claws are lost through autotomy. It is consistent with the view that the animals experience pain and distress as a result of declawing. Subsequent reduction in quality of life and survival rates if declawed animals are returned to the sea show that the declawing is unacceptable on welfare grounds and should not be permitted.

Return to sea

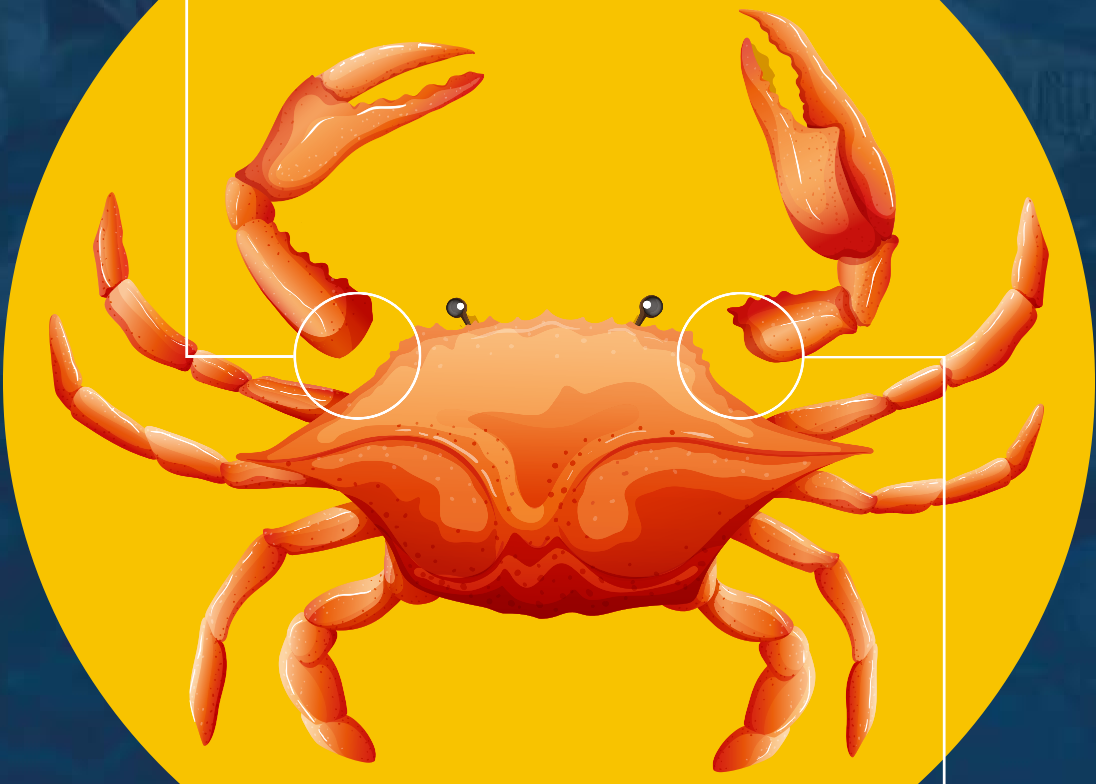
There is much evidence to show that crabs who are returned to sea following manual removal of one or both claws experience seriously poor welfare. They face impaired ability to feed, including restricted dietary choices, being unable to access key sources such as bivalves and larger prey [100,101], which in turn may adversely affect claw regeneration. They are also less able to fight or defend themselves, or compete for important resources such as territory, shelter or mates [102]. This together with the impact of the often-large wounds [101] resulting from the declawing process, leads to general increased disease prevalence and often high mortality [98,101]. Whilst the removal of both claws has a greater impact overall, these difficulties are still suffered if one claw is removed. Taken together, this evidence suggests the crabs' quality of life is seriously damaged after declawing. **Hence, contrary to popular belief, it is clear that returning manually declawed crabs to the sea is neither sustainable nor ethically acceptable and should not be practised**.

> Crustacean Compassion recommends that neither the practice of manually removing one or both claws from live crabs or other decapod crustaceans post harvest, nor subsequently returning them to the ocean, should be permitted.

Declawing

Declawing is the manual removal of one or both claws from a decapod crustacean, most commonly crabs.

Manual removal of the claws induces physiological stress responses (such as elevated lactate, glucose and muscular glycogen mobilisation), impairment of feeding and poor survival outcomes indicative of seriously impaired welfare. Manually declawed crabs also show behaviours indicating an awareness of the resulting wounds, as they touch the wounded area or shield it with their remaining legs. It is consistent with the view that the animals experience pain and distress as a result of declawing.



There is much evidence to show that crabs who are returned to sea following manual removal of one or both claws experience seriously poor welfare. They face impaired ability to feed, including restricted dietary choices, being unable to access key sources such as bivalves and larger prey, which in turn may adversely affect claw regeneration. They are also less able to fight or defend themselves, or compete for important resources such as territory, shelter or mates. This together with the impact of the often-large wounds resulting from the de-clawing process, leads to general morbidity and often high mortality.

Whilst the removal of both claws has a greater impact overall, these difficulties are still suffered if one claw is removed.

Claw nicking

Claw nicking involves fracturing the apodemes and cutting the tendons in the dactyls of the claws, resulting in an open wound with heightened susceptibility to infection [26]. It also causes damage to the internal claw tissues, haemolymph loss and compromise of defence mechanisms [26,120]. The cumulative effect of these reduces resilience to the many stressors experienced during capture, holding and transport.

Significantly elevated levels of immune response indicators (total pathologies and granulocytes), exacerbated stress response [121] and higher levels of stress indicators (including glucose and lactate) [120] have been found in nicked crabs. All these impacts weaken the crabs [122] and diminish their chances of survival [25]. **Research shows higher mortality rates were recorded in nicked crabs (83%) compared to non-nicked crabs (16.7%) over 14 days at the same temperature [121]. There are negative commercial implications of this practice as well as the welfare harm, with higher levels of necrosis and reduced quality of claw muscles from nicked crabs [120].**

Claw nicking

Claw nicking involves fracturing the apodemes and cutting the tendons in the dactyls of the claws, resulting in an open wound with heightened susceptibility to infection. It also causes damage to the internal claw tissues, haemolymph loss and compromise of defence mechanisms. The cumulative effect of these reduces resilience to the many stressors experienced during capture, holding and transport.

Significantly elevated levels of immune response indicators (total pathologies and granulocytes), exacerbated stress response and higher levels of stress indicators (including glucose and lactate) have been found in nicked crabs.

All these impacts weaken the crabs and diminish their chances of survival

There are negative commercial implications of this practice as well as the welfare harm, with higher levels of necrosis and reduced quality of claw muscles from nicked crabs.

Claw banding

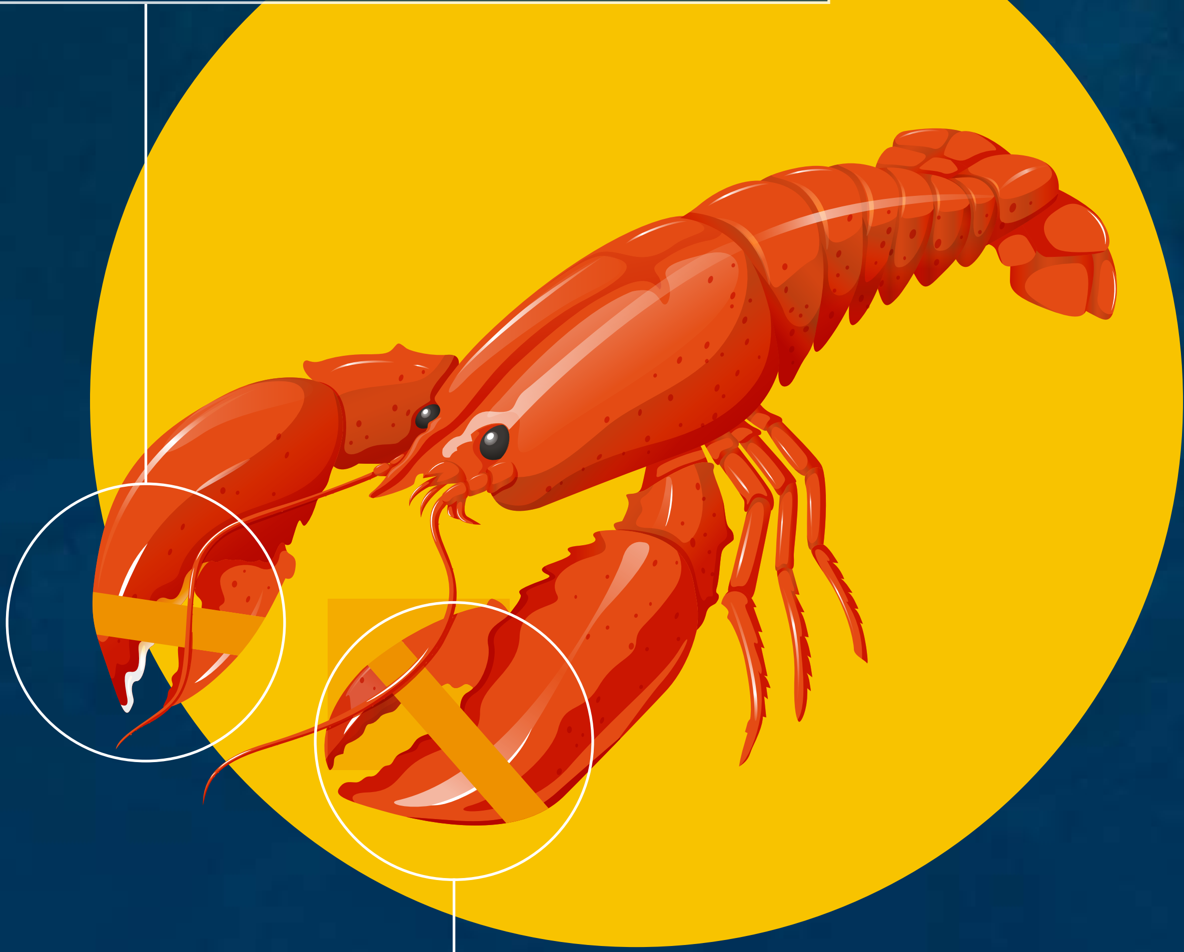
Claw banding is also used to immobilise the claws of crabs and lobsters. It is less invasive than nicking, avoiding some of the pathologies associated with physical wounding and appearing not to affect haemolymph indicators of stress [119]. However, it is still highly restrictive and prevents expression of natural behaviour [20,123,124]. In addition, long term banding causes muscle atrophy, inhibits natural feeding and threat/defence behaviour and can distort or weaken claws in moulting animals [20,123].

Given the welfare harms caused by claw immobilisation, the use of handling, storage and transport practices that avoid the need to restrict claw use in decapod crustaceans should be promoted. Due to the clear evidence of its negative impact on welfare, claw nicking should be prohibited and where essential for the avoidance of injuries to the animals, claw banding could be used instead. However, as banding also results in restriction of natural movement and behaviour with associated stress for the animals, banding should not be used for prolonged periods of storage, and more welfare-friendly alternative approaches to avoiding welfare problems associated with fighting and injury between captive decapod crustaceans should be developed and applied in practice.

Claw banding

Claw banding is also used to immobilise the claws of crabs and lobsters. It is less invasive than nicking, avoiding some of the pathologies associated with physical wounding and appearing not to affect haemolymph indicators of stress.

Claw banding is highly restrictive and prevents expression of natural behaviour. Banding should, therefore, not be used for prolonged periods of storage, and more welfare-friendly alternative approaches to avoiding welfare problems associated with fighting and injury between captive decapod crustaceans should be developed and applied in practice.



In addition, long term banding causes muscle atrophy, inhibits natural feeding and threat/defence behaviour and can distort or weaken claws in moulting animals.

Eyestalk ablation

Eyestalk ablation is the procedure of the removal or destruction of one or both eyestalks of decapod crustaceans. It is most commonly carried out on breeding female shrimps or prawns. It is often done without anaesthetic and is performed in order to increase egg production and reproductive success of broodstock, since the eyestalk contains glands which regulate the ovaries [104,105].

But there is clear evidence that the practice is also associated with serious harm to the animals, both short and long term. These include significant disruption of sensory perception and physiological, metabolic, hormonal and immune system function [104,106,107], high mortality [104,106] and erratic movement/swimming [108]. In addition, the display of peri- and post-ablation behaviours such as tail flicking, rubbing the affected area and flinching [108,109] are consistent with the ablated animals experiencing pain. The fact that such behaviours are reduced following application of anaesthetic [108] provides further support for this assertion.

The level of harm caused by the different commonly used eyestalk ablation methods – including ligation, cauterisation and slitting/pinching – may vary with method and species [109], and the impact on welfare of single eyestalk ablation is generally less severe than double ablation [106].

This strong body of evidence, indicating the multiple welfare concerns experienced by the large numbers of animals subjected to eyestalk ablation, underpins the view that this practice is completely unacceptable and should be replaced with non-invasive alternatives

Non-invasive alternatives

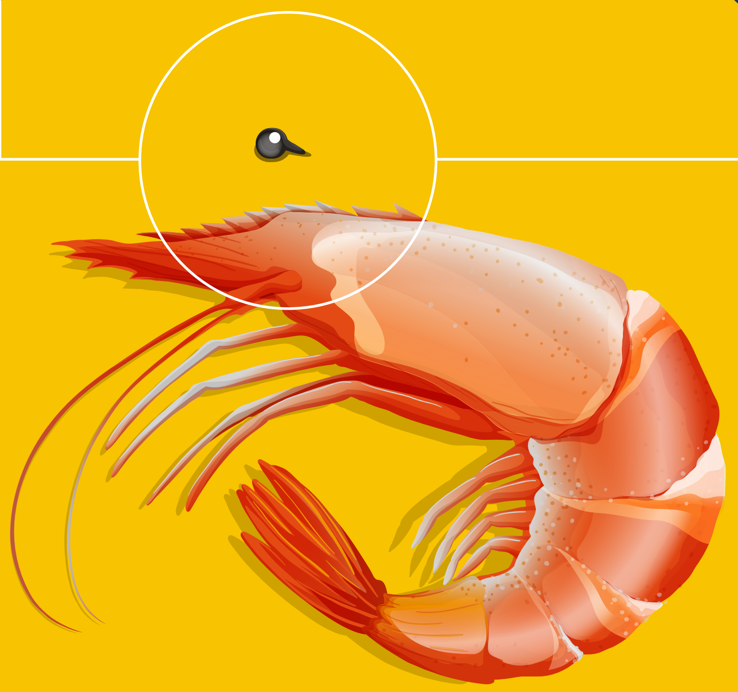
Recent scientific have shown that it is possible to achieve enhancement of fecundity in captive decapod broodstock with ablation. Moreover, there are indications that the quality and survival rates of eggs and offspring of ablated females may be inferior compared with intact animals [110,111] and that other reproductive and production parameters (such as numbers of eggs per female) are not necessarily improved by ablation [104,105,111,112] and may

Continued on page 46 →

Eyestalk ablation

Eyestalk ablation is a procedure involving the removal or destruction of one. of one or both eyestalks of decapod crustaceans. It is most commonly carried out on breeding female shrimp or prawns. It is often done without anaesthetic and is performed in order to increase egg production and reproductive success of broodstock, since the eyestalk contains glands which regulate the ovaries.

But there is clear evidence that the practice is also associated with serious harm to the animals, both short and long term. These include significant disruption of sensory perception and physiological, metabolic, hormonal and immune system function, high mortality and erratic movement/swimming.



In addition, the display of peri- and post-ablation behaviours such as tail flicking, rubbing the affected area and flinching are consistent with the ablated animals experiencing pain. The fact that such behaviours are reduced following application of anaesthetic provides further support for this assertion.

The level of harm caused by the different commonly used eyestalk ablation methods – including ligation, cauterisation and slitting/pinching – may vary with method and species and the impact on welfare of single eyestalk ablation is generally less severe than double ablation.

be worsened in some respects such as increased energy demands [113], eventual loss in egg quality and high mortality [114].

This suggests that its use may involve economic and production-related shortcomings in addition to the welfare concerns. There is also evidence that ablation can be replaced by non-invasive alternatives. Adjustments to the animals' environment, including lighting/photoperiod, water temperature, diet, stocking density and tank characteristics [115–117], as well as changing the ratio of males to females (from the commonly used 1:1 to 1:2) [110], can result in comparably enhanced reproductive performance such as increased egg and offspring production and viability, and improved survival rate of the females themselves. The exact nature of the farming system also impacts on productivity [118]. The impact on welfare of these environmental manipulations would need to be explored and considered before application.

However, the availability and potential efficacy of these non-invasive options together with the clear evidence of the serious negative ablation-linked welfare impacts, strongly underline both the urgent need to prohibit the practice of eyestalk ablation and the feasibility of replacing it with alternative approaches.

Claw immobilisation

The claws of large decapod crustacean species such as crabs and lobsters are often immobilised post-capture for the ease of handling and to prevent cannibalism, fighting and claw damage during storage and transport [28,96,119,120]. Methods commonly used to achieve this include claw nicking or claw banding.

> Crustacean Compassion recommends that eyestalk ablation of any decapod crustacean for any purpose is unacceptable and should be prohibited.

V-notching

Tail (or v-) notching is a fishery management practice widely used to delay fishing mortality of berried female lobsters allowing them to continue reproducing, thus maintaining brood stocks. The "notch" is created by removing a small triangular piece from the second or forth uropod (section of tail fan) after capture before returning the animal to the sea. In the event of inadvertent recapture, these animals can then be quickly and easily identified and once more returned to the sea. Legislation in the UK makes it illegal to land, hold, or sell these lobsters.

Whilst undertaken for conservation purposes, the removal of tissue from live lobsters leads to the risk of pain and distress. It may also result in increased susceptibility to disease, lowered resilience to environmental stressors, and higher rates of mortality. Studies of phylogenetically similar crayfish have identified somatosensory neurones (that facilitate the perception of touch, pressure, pain, temperature, movement, and vibration) and sensory hairs in all uropods located at the extremities of the tail fan [219]. Harmful stimuli have been shown to elicit behavioural responses that indicate pain, including an immediate reflexive tail flick [220] or tail withdrawal.

Although intended as a means of sustaining and protecting the species, the tail (or v-) notching technique should also be considered with the welfare of individual animals in mind. This includes pain and stress caused by handling, blood loss, risk of disease and infection (for example, through inappropriate and/ or poorly maintained equipment), and loss of proprioception (i.e., awareness of the position and movement of the body) which may affect predator awareness, locomotion, and ability to feed once returned to the sea.

Where tail (or v-) notching is carried out, the handling of animals should be undertaken carefully and kept to the minimum necessary, while only clean, sharp implements used specifically for this technique should be used. Further, alternative techniques that avoid mutilation and its associated welfare issues whilst preserving the lives of berried females should be developed.

Focus on holding and storage

Holding duration

After capture, decapod crustaceans are held in on-board storage and in holding facilities for varying periods of time, which can range from days to months. The length of time for which live decapod crustaceans are held in storage influences the nature and extent of the impact on welfare. Live holding in tanks over varying periods of time is a major part of the post-harvest process in lobster fisheries. The aim is often to allow purging of nitrogenous waste (see: 'Pre-transport holding and purging' Position Statement in Transport section for details) and recovery from stress due to factors such as air exposure, disturbance and environmental variations during capture and handling [15], ahead of onward transport.

Immune parameters in lobsters during a 10-day holding period change between days one and four, suggesting that physiological adjustments still occur for up to four days post capture [15]. Other research shows that after several weeks of storage in recirculation tanks, lobsters show a marked degradation of the muscle myofibrillar proteins [21]. While in addition, the extent of exposure to negative experiences prior to reaching holding/storage facilities also influences survival rate and duration during storage [125].

Fasting affects welfare and survival rates

The duration of live storage in water tanks, along with chilling rates, also significantly affects survival rates in prawns [126], with longer periods of storage and faster chilling leading to increased mortality. Other studies suggest that some crabs can be held for up to 89 days without food, though physiological measures raise concerns about the potential distress and nutritional status of the animals [127]. Research evaluating the effects of long-term starvation and temperature on lobsters kept in holding tanks for 24 weeks indicates that whilst the animals can survive a prolonged period without food, it compromises their physiological condition and potentially impairs immunological capacity so should be avoided [24]. The impact of long storage times is also affected by the stocking density within holding tanks, with high densities increasing the negative impact of long duration [128].

> In summary, evidence clearly indicates that during storage of live decapod crustaceans, the risks to welfare increase with duration of holding, especially in the absence of feeding. Any storage of these animals should therefore be kept to the minimum necessary. Moreover, logistical and marketing infrastructure is adjusted to avoid long periods of holding, along with optimising the conditions to which the animals are exposed.

Mixing species

In some situations, including during live storage in tanks in supermarkets [129], decapod crustaceans are often held together with other incompatible species of aquatic animals. This mixed stocking places the animals in close proximity to others they would not normally choose to be near in their natural environment usually without the opportunity to move away or hide. This is a key source of stress during storage [130] leading to mobilisation of energy substrates and physiological disturbances [129].

The practice of mixing different species of decapod crustacean with each other and/or with other aquatic animals causes significant stress. It should be avoided at all times, and each individual species should be kept apart from others during storage and transport, regardless of duration.

Stocking density

In many storage situations, including holding facilities [25] and at point-of sale retailer outlets [20], decapod crustaceans are closely confined at high stocking densities resulting in a number of welfare challenges. Some species are more sensitive than others to overcrowding [128], especially those (such as some lobsters) that are naturally solitary [131] and/or territorial [123]. In such cases, forced proximity to others with no ability to move away both prevents natural behaviours and leads to stress [131].

Overcrowding can also have negative physical impacts, with prawns held in tanks showing significantly greater degradation of antennal length and rostral spine length at higher compared with lower stocking densities [132]. In some crabs, increasing stocking density during storage raises the risk of cannibalism, injuries and mortality [133,134]. In holding and storage centres where lobsters are kept at high densities, the resulting build-up of nitrogenous wastes and depletion of dissolved oxygen leads to mortalities [135], whilst studies of crabs stored over a three-week period indicate the importance of keeping stocking densities below certain levels in order to avoid the risk of mortality [128].

The clear evidence of the negative impact on welfare of high stocking densities during holding and storage of decapod crustaceans indicates the need to ensure that adequate species-specific space allowances are provided during containment. There should be sufficient space to allow the animals room to move away from others to avoid antagonistic interactions, and to enable water quality to be maintained at appropriate levels. Optimum species-specific stocking densities that enable expression of natural behaviour and avoidance of negative welfare impacts currently seen in overcrowded holding and storage conditions, should be established and implemented in practice, particularly when storage is of long duration.

See also:

Section 5: Focus on mutilations and claw immobilisation

- Eyestalk ablation
- Claw banding
- Claw nicking

Section 6: Focus on transport

- Pre-transport holding and purging

Section 8: Common welfare issues throughout the sea to plate journey

- Air exposure
- Light exposure and lack of shelter
- Temperature fluctuations and extremes
- Inappropriate water quality

Focus on transport

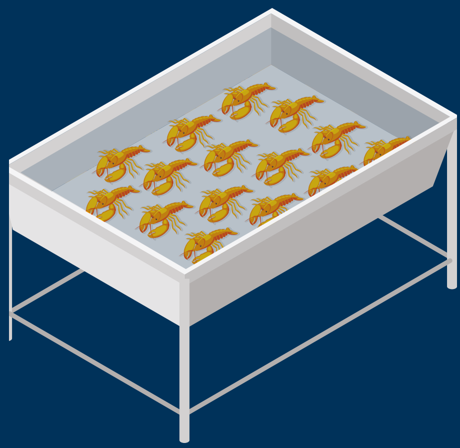
Pre-transport holding and purging

Prior to transportation, decapod crustaceans are often cooled, fasted and purged. For example, freshwater crayfish are generally held in tanks with flow-through water and biological filtration to allow 24 hours of purging prior to transport [28]. Whilst reduction of the accumulation of waste products in transit can benefit the animals physiologically, the hunger caused by the feed restriction can lead to increased aggression and cannibalism in some species, with associated risk of harm to other animals [136].

These behavioural consequences are not seen in all species [22] but other indicators of poor welfare, including severe decreases in the hepatosomatic index (HI) in fasted crabs [127] and lowering

Purging

Purging: Prior to transportation, decapod crustaceans are often cooled and fasted, a process in which the animals are held with little or no food for a period of time in water, during which time they excrete nitrogenous waste which reduces its accumulation during transport [28]. Sufficient changes of water or flow systems to ensure removal of the nitrogenous waste during the purging process is important to avoid negative effects on the animals.



of HI in those fed twice a week [22], suggest that these practices could both undermine nutritional status and cause distress during live holding.

Research evaluating the effects of long-term starvation and temperature on lobsters kept without food in holding tanks for 24 weeks indicates that whilst the animals could survive a prolonged period without food, it compromises their physiological condition and potentially impairs immunological capacity so should be avoided [24].

Re-immersion

Re-immersion of decapod crustaceans into water in a stocking centre immediately after fishing and prior to further onward travel has been shown to be beneficial to welfare. Research indicates that the stress produced by transport of crabs to shore is alleviated after 48 hours of re-immersion in aquaria with seawater re-circulation, facilitating survival during further transportation [137]. Survival rates and physiological parameters in prawns following 16 hours of transport are also significantly affected by the pre-transport holding conditions, with increased salinity in holding tanks resulting in lower haemolymph ammonia and mortality at the end of the journey [37].

The temperatures experienced ahead of transport also have impacts. Cooling of decapod crustaceans is commonly undertaken pre-transport, with lower temperatures generally reducing mortality. For example, during 16 hours of travel, significantly higher survival rates are achieved in pre-chilled freshwater prawns (92% survival) than in those not chilled before packing (67%) [37]. It must be noted however that chilling can cause significant welfare compromises for all decapod species and should not be undertaken without consideration of this.

The overall impact of the conditions experienced pre-transport on the welfare and survival of decapod crustaceans during subsequent transportation is very clear. It is therefore critically important to take a properly evidence-based approach to understanding and applying the most appropriate species-specific practices in the period between capture and transport. This is positive for animal welfare and also has commercial benefits. As a general rule, immersion pre-transport is recommended. However, purging, especially for prolonged periods, can lead to welfare concerns, though may be advisable on balance if transport containers lack effective water flow systems that remove nitrogenous waste in transit. Nevertheless, it is important to note that purging is only necessary in order to compensate for inadequacies in transport conditions and practices and would not be needed if holding facilities in transit were improved. Where knowledge gaps exist, (e.g. optimal transport conditions and systems capable of removing sufficient quantities of nitrogenous waste for the duration of journeys), these should be urgently addressed through focused research and development and swift application of learnings in practice.

Duration and complexity of journeys

The impact of live transport on animal welfare is directly linked to the duration of travel, with long journeys being likely to have more detrimental effects than short ones. The impact of journey length on animal welfare is a widely accepted concern, with European legislation aimed at protecting various species in transit stating that ‘for reasons of animal welfare, the transport of animals over long journeys, including animals for slaughter, should be limited as far as possible’ [138]. The ability of decapod crustaceans to withstand long journeys without unrecoverable increased disease prevalence and mortality depends greatly on the species and on the transport conditions. Overall stress, increased disease prevalence and mortality increase with duration of travel [35], both for animals transported whilst exposed to air [137, 123] and for those immersed in transit.

Longer journeys also increase the risk of starvation, especially when there has been a long period of food deprivation pre-transport as can occur due to purging though this depends greatly on the species. Some crabs can survive for weeks without food [140] but other species such as prawns suffer significant energy depletion and associated physiological changes if food-deprived for much shorter periods [141]. The severity of physiological disturbance – with associated suffering – and mortality levels due to starvation are therefore dependent on journey duration and the period of food deprivation pre-transport.

Higher temperatures tend to increase the negative impact on most species, as do physical disturbances such as vibrations. The additional stressors associated with more complex journeys involving multiple phases and/or means of transport, including transfer of containers between vehicles and/or of animals between containers, also affect the duration of travel that can be tolerated. In addition, re-immersion of crabs in a stocking centre immediately after fishing and semi-dry transport to shore has been found to enable recovery from stress within 48 hours, and hence to facilitate survival during further transportation [137].

Unaccompanied Delivery (mail/post)

All transport involving live decapod crustacean needs to be accompanied by suitably trained and knowledgeable personnel with packaging clearly labelled as containing live animals. For example, some decapods are sent through post, with unknown conditions, potentially unsuitable packaging, unknown duration and uncertain treatment at the destination. This is clearly associated with very high risk of negative welfare outcomes.

The correlation between both journey duration and complexity, and the risk and severity of impact on animal welfare, is clear. Crustacean Compassion therefore reccomend that any live transportation of decapod crustaceans should be planned and implemented to ensure the minimum possible journey times (including loading and unloading times). Journeys should also follow the most direct, least complex routes possible between dispatch sites and destinations.

In-water transport

Transportation in water via immersion in various designs of tanks, viviers or other containers, including plastic bags, is common practice for many species of decapod crustacean [28]. Whilst immersion is a natural state for decapod crustaceans, key considerations that impact on welfare and survival during in-water transport include the design and functional capabilities of the containment systems used and their ability to maintain appropriate water quality and temperature ranges [28,36,142]. For example, prawns have significantly different survival rates when transported in water at 21°C (97% survival) and 26°C (24%).

Maintenance of species-appropriate salinity is also crucial to welfare and survival [123]. Low oxygen levels and accumulation of excreted toxins occur in the absence of effective filtration and water circulation systems in transit, resulting in significant negative impact on the welfare of transported decapod crustaceans [26,29]. Mortality rates during journeys in seawater with insufficient dissolved O2 can be higher than during 'in air' transportation, depending on temperature [29,35], with 25% mortality noted in crabs transported in water at 12°C compared with 4% mortality in air at 4°C [35]. Studies have also shown that hypoxic water in transit leads to raised bacteraemia in crabs [143], whilst levels of physiological stress indicators at the end of transport of water-immersed crabs can be greater than those seen following transport in air under high humidity conditions [144]. Control of the concentrations of nitrogenous waste breakdown products (mainly ammonia) is also key to successful maintenance of immersed decapod crustaceans during transport and storage but is difficult to achieve in closed systems over long periods [142].

In summary, providing and maintaining species-specific water quality, salinity and temperature ranges during transport of decapod crustaceans in water is crucial to their welfare and survival. It should be mandatory to ensure that existing knowledge of the biological needs of each transported species is applied when developing and using equipment and on-board operating systems, to ensure that they are demonstrably capable of providing, monitoring and maintaining the most suitable water quality and environmental parameters for the species throughout transportation.

Containment methods

Decapod crustaceans in transit are subjected to a number of challenging experiences due to the mode of containment and associated conditions such as high stocking densities and stacking. Crabs, for example, are sometimes transported at densities of 1 kg/litre seawater in tanks, with the animals at the bottom being compressed by the others and by handlers [26].

Some research indicates no difference in the vigour values between crabs either stacked on top of each other or with free mobility during eight hours transport in semi-dry conditions [137]. However, other studies [26] on mortality rates during post-transport recovery of crabs stacked in a tank during 58 hours of transport show that those from the bottom of the tank start to die sooner (within 48 hours) than those from the top. The higher levels of haemolymph lactate in the tank bottom crabs at this time possibly explains this difference, though crabs from the top of the tank ultimately had slightly higher mortality overall (10.7% compared with 8.9% for those placed at the bottom of the tank). After transport, crabs at the bottom of the tank have more missing legs than those at the top, which could indicate additional stress-induced autotomy. Also, amongst the crabs transported at the bottom of the tank, males had more missing claws than females, possibly related to the more aggressive behaviour typical of males [145]. Evaluation of the effect of stocking density on prawns after 24 hours in water in model transport containers indicates no significant difference in prawn survival at three different densities (25, 50 and 100 g/L). However, although concentrations of dissolved oxygen and nitrite appear unaffected by density, water quality is more impaired at higher stocking rates, with concentrations of nitrogenous materials rising significantly as densities increase [36], heightening risks to welfare in transit. The social stress caused by confinement of animals in close proximity in containers leads to aggression and fighting among some species [28,145]. This in turn leads to the use of methods – such a claw nicking or banding – aimed at reducing injury but which add additional welfare challenges.

The exact nature of the containment methods and associated parameters during transport clearly have important implications for the welfare of decapod crustaceans. Crustacean Compassion advocates that any such practices that expose animals to physical, physiological and behavioural challenges, such as high stocking density, should be avoided or modified to take account of species-specific characteristics and needs in order to reduce the negative impact on welfare.

Packaging

Various different packaging materials are used to facilitate maintenance of a damp environment for decapod crustaceans transported out of water. There is limited information on their efficacy and suitability but studies indicate that the type of packaging does affect welfare. Some guidelines accept use of seaweed or kelp as a suitable moist packaging substance [146]. However, it can release noxious gases as it decays with unknown consequences for the animals [137,146]. The use of alternatives including burlap bags as moist packing material for long-haul transport of crabs decreases transport-related indicators of stress (such as haemolymph metabolites) and enhances subsequent recovery compared with kelp packaging [137].

Transportation of large live decapod crustaceans, such as lobsters, by air is often in cardboard boxes in refrigerated and moist conditions, with separation between individuals [25]. Some crabs transported by air freight on journeys up to 24 hours are packed in STYROFOAM™ sealed boxes with coolers. However, research has shown this can result in high mortality rates (e.g. 40%) [35]. Other recommended packaging for emersed crabs includes packing between layers of moistened wood shavings, newspaper or marsh grass in ventilated boxes under controlled humidity (70%) and low temperature [28,146]. Packaging in insulated containers containing moist foam or wood shavings and cooling packs is recommended for transportation of freshwater crayfish [147,148]. The ability to maintain appropriate species-specific conditions – such as temperature – within packaging and containers is essential, with a positive significant correlation seen between increased disease prevalence and mortality in lobsters and internal carton temperature [149]. Some form of containment within water tanks, such as confinement of prawns in perforated containers stacked within transport tanks, is sometimes deemed to be advantageous in live transport [36] while prawns and shrimps are sometimes packed in oxygenated water in plastic bags [28].

There is a clear need to ensure species-specific suitability of transport packaging methods in terms of their ability to maintain appropriate environmental conditions such as humidity/moisture and temperature, and ensure avoidance of risks to welfare, such as those posed by deterioration of the materials in transit. Robust evidence is currently limited regarding the most suitable packaging materials and methods to use to protect decapod crustacean welfare during transport. Crustacean Compassion therefore recommends further strengthening of knowledge about the impact on welfare of different transport packing methods, and swift application of learnings in practice to ensure better protection of animal welfare.

Physical disturbances

Transported decapod crustaceans experience a range of physical disturbances [28], which can cause trauma and stress and compound the effects of other transport-related stressors. For example, the levels of disturbance have been found to influence the ability of lobsters to survive emersion during commercial shipment [125], while it is recommended that crayfish should be exposed only to minimal physical disturbances [23]. Research indicates that the increase in stress indicators such as Total

Haemocyte Counts, serum glucose, lactate and ammonium concentrations caused by emersion of nephrops, are further increased when the animals are shaken for one hour to replicate transport vibrations [150,151]. Mitigation e.g. through cushioning, could be easily and inexpensively implemented to reduce the impact and improve survival and recovery post transport [150].

A range of handling processes immediately before, during and at the end of transportation, including placing animals into packaging/containers, transfer of containers onto or between vehicles/means of transport and unloading post transport can all cause stress and physical trauma, indicating the importance of minimising any handling and undertaking it in a careful and considered way [130]. Noise can also harm decapod crustacean welfare. Studies indicate that low-frequency ship and boat noise as well as white noise and pure tones can have a variety of biological impacts and an increase in some behaviours (for instance locomotion) and stress [152]. For example, a rise in haemolymphatic bioindicators of stress along with increased locomotor activities are seen in lobsters exposed to boat noise [153], while noise also impacts negatively on the immune parameters of stress in lobsters [154].

In summary, studies focused on assessing the impact of physical disturbances – including vibrations/shaking, noise and vigorous handling – on the welfare of decapod crustaceans in transit confirm that they pose a significant additional stressor in themselves. They can also worsen the negative effects of other stressors experienced during transport. Crustacean Compassion recommends that practices should be adapted to mitigate against physical trauma (e.g. road vibrations) and ensure reduction or avoidance of noise exposure on all journeys involving live decapod crustaceans in order to improve welfare and survival.

See also:

Section 5: Focus on mutilations and claw immobilisation

- Claw nicking
- Claw banding

Section 6: Focus on holding and storage

- Holding duration

Section 8: Common welfare issues throughout the sea to plate journey

- Air exposure
- Light exposure and lack of shelter
- Temperature fluctuations and extremes
- Inappropriate water quality

Common welfare issues throughout the sea to plate journey

Air exposure

Decapod crustaceans are well adapted to living in water so the exposure to air (emersion) experienced during capture, holding and transport inevitably leads to a number of welfare challenges [155]. Many commercially important decapod crustaceans, especially subtidal dwelling species, are not exposed to air in their natural environment, yet many are transported out of water for long periods of time. A combination of handling and prolonged air exposure also further exacerbates stress reactions [155].

There are significant species-specific [156–158], sex-specific [159] and moult stage-specific [125] differences in the nature and severity of the impact of air exposure on welfare. However, whilst some animals are better able to mitigate the consequences of emersion [28,156], it constitutes a major stressor [31] associated with seriously negative effects. These include reduced capacity to regulate respiratory gas exchange, acid-base balance and nitrogenous waste excretion [156–158].

As aquatic animals, decapod crustaceans breathe underwater using gills, but emersion impairs gill function and disrupts oxygen consumption. In turn, disruption of oxygen consumption is associated with many physiological and metabolic changes such as increases in lactate and acidosis, raised crustacean hyperglycaemic hormone, haemolymph glucose and ammonia accumulation in many species of lobsters [28,79,155], nephrops [59,151,160], shrimps [161,162] and crabs [163,164].

The rise in ammonia levels is exacerbated by low levels of humidity during emersion [165], with maintenance of high humidity (90 – 95%) also being essential to avoid drying of the gills which can cause irreversible damage [142]. The build-up of nitrogenous waste during emersion, along with the other physiological disturbances and imbalances, are worsened by higher temperatures [59] and can ultimately result in significant levels of mortality [59,161,162,166,167]. In surviving animals, the physiological changes can also lead to short- and long-term depression of the immune system [59,155,168–170], raised bacteraemia, increased susceptibility to infection and acceleration of disease conditions [28,155,171], with implications for both animal welfare and food quality and safety.

Air exposure during the unloading process post-transport has been identified as a key stressor for crabs [26] and air exposure of nephrops results in effects on physiological, immunological and pathological parameters [59]. The duration of air exposure and desiccation during holding significantly influences welfare and survival. Mortality rates of 37.5% and 87.5% in shrimps have been seen after desiccation for five hours and ten hours respectively [161], and air exposure for as little as ten minutes leads to raised blood glucose concentrations – an indicator of metabolic stress – in juvenile prawns [132]. The oxidative status of crabs can be severely affected after six hours of air exposure [62]. In addition, re-immersed lobsters take five to eight hours [172] or longer [166] to recover from exposure to handling and emersion [172], and can show poor survival rates (25%) 24 hours after re-immersion in holding tanks following a period of 12-14 hours air exposure in transit [125]. The severity of the impact is greater [163] and the duration of the recovery period is longer [172] at higher temperatures. However, practices such as displaying lobsters in air on ice in food retailers and live markets are also likely to result in serious suffering [20].

Overall, there is a wealth of scientific evidence to show that exposing decapod crustaceans to air during transport (and in other situations) is frequently associated with serious acute and chronic welfare problems, often resulting in mortality. Some of the most serious impacts could be mitigated to some extent, and for some species, by optimising environmental conditions to better meet species-specific needs, and by avoidance of disturbance. Hence, only with very strictly controlled conditions in which temperature, humidity, containment method etc. are optimised throughout travel for the species involved, should emersion in transit be undertaken. However, even then, if meaningful reduction in suffering and death is to be achieved, various other provisions need to be applied. For example, the frequency and duration of emersion throughout the capture to killing process must be kept to an absolute minimum. In addition, emersion should be replaced with in-water holding methods when involving longer periods of storage, provide optimal conditions (temperature, humidity) when undertaken and be avoided completely whenever possible.

Light exposure and lack of shelter

In their natural environments, many species of decapod crustaceans are not normally exposed to bright light and actively seek to avoid it, including through moving to dark hiding places. For example, lobsters are primarily nocturnal animals and emerge from cover as darkness falls to forage for food, before returning to shelter when the light level starts to rise [123] and remaining there, leaving only occasionally, during light periods [173]. This clearly indicates their preference to avoid strong light. Crabs and crayfish are also sensitive to sunlight and should be kept in shaded environments with no bright light exposure [23,28]. However, from capture onwards, they are often exposed to sudden and bright light for varying periods of time. This includes during on-board and pre-transport holding, 'sorting' and packaging, during the journey itself and during loading/unloading and holding post-transport. Exposure to light can have a variety of negative effects on decapod crustaceans [174] including light-induced photoreceptor damage in the eyes which tends to be progressive and irreversible [175].

In addition to avoiding light, decapod crustaceans have a clear preference for shelter [176], with studies of various species including crabs [177], prawns/shrimps [108] and lobsters [123,173,178] providing clear evidence of the importance of sheltering/hiding to these species. But they are often unable to hide due to lack of provision of shelter in some holding, transport and storage systems, most likely resulting in stress and compromising welfare [179]. For example, poor practice in this respect is evident in retailer outlets, including in the UK [124] and Europe [20], where lobsters and crabs in tanks are exposed to direct, bright, intense light with no dark areas for refuge. This stressful situation is worsened by other disturbances likely to be experienced by decapod crustaceans in such retail environments [124] and can reduce survival rates [180].

The short-term and sometimes long-lasting harm to welfare associated with both exposure to bright light and the failure to provide opportunities to shelter/hide, – add to other stressors experienced during the storage and transit periods. This contributes to poor welfare, increased disease prevalence and mortality. This indicates a clear need to shield animals from sun exposure and sudden and bright lights. The definite preference of many decapod crustacean species to avoid light and seek shelter should be taken into account in designing, developing and implementing holding and transport systems and processes.

Temperature

Temperature – alone and through its interaction with other parameters – has a significant influence on the welfare and survival of decapod crustaceans during holding and storage [24,128,140,172].

The temperature during holding can have substantial negative effects on the subsequent product quality, likely to be related to the deterioration of muscle structure and hence having serious

welfare implications. It occurs more markedly and earlier in crabs kept at higher temperatures with even a 5°C difference (10°C vs 5°C) being influential [140]. In some crabs, increasing temperature (and stocking density) during storage increases the risk of cannibalism, mortality, and injuries [133,134].

Although species vary in their level of sensitivity to change [133,134], some are very sensitive both to fluctuations in temperature and to holding at temperatures at the extremes of the normal range to which they are adapted [133,134].

The rate of change of temperature experienced within storage tanks also has a major impact on welfare and mortality. For example, the chilling rates of tank water from 25-15°C during live storage significantly affects survival rates of freshwater prawns over different durations, with slower chilling (over eight hours) enabling storage for twice as long (16.5 hours) without significant mortality than fast chilling (over a two-hour period) [126]. Similarly, recovery and survival of crabs following transport can be facilitated by gradual acclimatisation – rather than a sudden change – to holding tank temperature [29].

During transport, temperature also critically affects stress, physiology, behaviour and survival rates of decapod crustaceans, including lobsters [125,149,181,182], crabs [33,35,163,183], nephrops [160] and prawns [36].

The optimal temperature varies with species [183,184] and, where there are gaps in knowledge, can be identified through appropriate research [163]. Although transport at below-optimal species-specific temperatures can increase mortality [163], many studies have demonstrated that at lower temperatures, decapod crustaceans tend to have lower levels of ammonia and lactate, lower energy demands [33,35,183], can better maintain energy homeostasis and have better survival rates [36,149,184].

However, this needs to be balanced against the risk of exposure to temperatures that are too low as this can also be harmful. Maintenance of temperatures within – though at the lower end of – each species' thermo-neutral zone should therefore be the aim.

Pre-cooling prior to transport can also prolong survival [185]. Conversely, rising temperature increases decapod crustacean metabolism, lowers oxygen concentrations in the body, and increases levels of ammonia and carbon dioxide [142]. The speed of cooling pre-transport is important. Rapid chilling can cause loss of legs and claws [28], so the recommendation is for slow cooling of crabs [186] and shrimps [146]. Temperature influences the ability to tolerate situations such as air exposure and handling in transit. Chilling of lobsters exposed to air for up to 30 hours by including ice in the shipping cases ameliorates the high heart rate and hyperventilation caused by the packing process and delays the onset of anaerobiosis (oxygen deficit) [181]. Similarly, the environment should be kept cool (and moist) to enable crayfish to be successfully transported in air [23]. Even small fluctuations in temperature have a highly significant impact on mortality rates in prawns transported in water, with survival at 21°C averaging 97% compared to only 24% survival at 26°C. [36]. The impact of high body temperature can also be long lasting post transport. Lobsters with higher body temperatures following transportation have higher levels of stress-induced physiological variables such as haemolymph glucose, lactate and pH than those with lower body temperatures, an effect that is sustained for as long as 96 hours after immersion in recovery tanks [144].

It is clear that both temperature levels and temperature fluctuations have a highly significant impact on the welfare and survival of decapod crustaceans during holding, storage and transport, both alone and in combination with other environmental conditions. It is crucial to identify, apply and maintain species-appropriate temperatures throughout, within ranges to which the various species are adapted. Slow acclimatisation when changes are required (for example, after chilling during transport) is essential to reduce stress, morbidity and mortality at this time, and should be facilitated through ensuring knowledge of species-specific needs, and frequent monitoring and management of temperature in all holding and transit situations. Scientific knowledge should be more effectively utilised and where necessary, current holding and transport practices and equipment adapted to ensure monitoring and maintenance of appropriate temperatures. Such an outcome would be of benefit both to the animals and commercially.

Water quality

Unsuitable water quality during storage and transport has a major negative impact on decapod crustaceans [130]. Many animals are unlikely to survive poor water quality [123], with certain species such as crayfish being particularly sensitive to changes [187]. In holding facilities decapods may be kept in water tanks for long periods of time. It is also common practice for many species of decapod crustaceans to be transported immersed in various designs of water tanks, viviers or other containers, including plastic bags [28].

Whilst immersion is a natural state for decapod crustaceans, key considerations that impact on welfare and survival in storage and during in-water transport include the design and functional capabilities of the containment systems used and their ability to maintain appropriate water quality and temperature ranges [28,36,142]. For example, prawns have significantly different survival rates when transported in water at 21°C (97% survival) and 26°C (24%).

Maintenance of ideal water quality is challenging, and parameters need to be checked regularly (daily is recommended) especially when stocking rates are high in the holding tanks [142]. Situations in which decapod crustaceans such as lobsters are held in overcrowded aquariums in retail outlets risk progressive worsening of water quality and welfare (and increases the microbiological risk), as evidenced by the poor or mediocre water cleanliness seen during research on conditions for lobsters held in fish shop tanks [20].

In particular, the maintenance of appropriate dissolved oxygen levels is critical to wellbeing and survival, with low levels being associated with serious negative impacts [188]. For example, changes in physiological indicators of hypoxic/metabolic stress are seen in freshwater prawns exposed to lowered dissolved oxygen levels [132,169]. Other research shows that the oxygen requirements of lobsters in live-holding tanks are significantly affected by other factors such as the level of exercise, handling and air exposure prior to immersion in the tanks, and temperature. A strong diurnal rhythm to oxygen consumption and an increase following feeding also occur [172], indicating the need to maintain optimal levels at all times.

Low oxygen levels and accumulation of excreted toxins occur in the absence of effective filtration and water circulation systems in transit, resulting in significant negative impact on the welfare of transported decapod crustaceans [26,29]. Mortality rates during journeys in seawater with insufficient dissolved oxygen can be higher than during 'in air' transportation, depending on temperature, [29,35], with 25% mortality noted in crabs transported in water at 12°C compared with 4% mortality in air at 4°C [35]. Studies have also shown that hypoxic water in transit leads to raised bacteraemia in crabs [143], whilst levels of physiological stress indicators at the end of transport of water-immersed crabs can be greater than those seen following transport in air under high humidity conditions [189].

Ensuring species-appropriate salinity and pH are also particularly important in safeguarding welfare – including immune function – and survival [190]. Control of the concentrations of nitrogenous waste breakdown products (mainly ammonia) is also key to successful maintenance of immersed decapod crustaceans during transport and storage but is difficult to achieve in closed systems over long periods [142].

In summary, providing and maintaining species-specific water quality, salinity and temperature ranges in holding facilities and during transport of decapod crustaceans in water is crucial to their welfare and survival. All holding facilities should, as a basic minimum requirement, ensure that levels of dissolved oxygen and other key parameters are maintained at species-appropriate levels throughout the storage period. Water quality must be assessed at least daily and necessary adjustments to management and equipment made accordingly. In addition, it should be mandatory to ensure that existing knowledge of the biological needs of each transported species is applied when developing and using equipment and on-board operating systems. These should be demonstrably capable of providing, monitoring and maintaining throughout transportation the most suitable water quality and environmental parameters for the species.

See also:

Section 4: Focus on capture

- Method of capture
- Bycatch
- Post-capture handling
- On-board holding and storage

Section 5: Focus on mutilations and claw immobilisation

- Declawing
- Claw nicking
- Claw banding
- Eyestalk ablation

Section 6: Focus on holding and storage

- Holding duration
- Mixing species
- Stocking density

Section 7: Focus on transport

- Pre-transport holding and purging
- Duration and complexity of journeys
- In-water transportation
- Containment methods
- Packaging
- Physical disturbances
- Unaccompanied Delivery

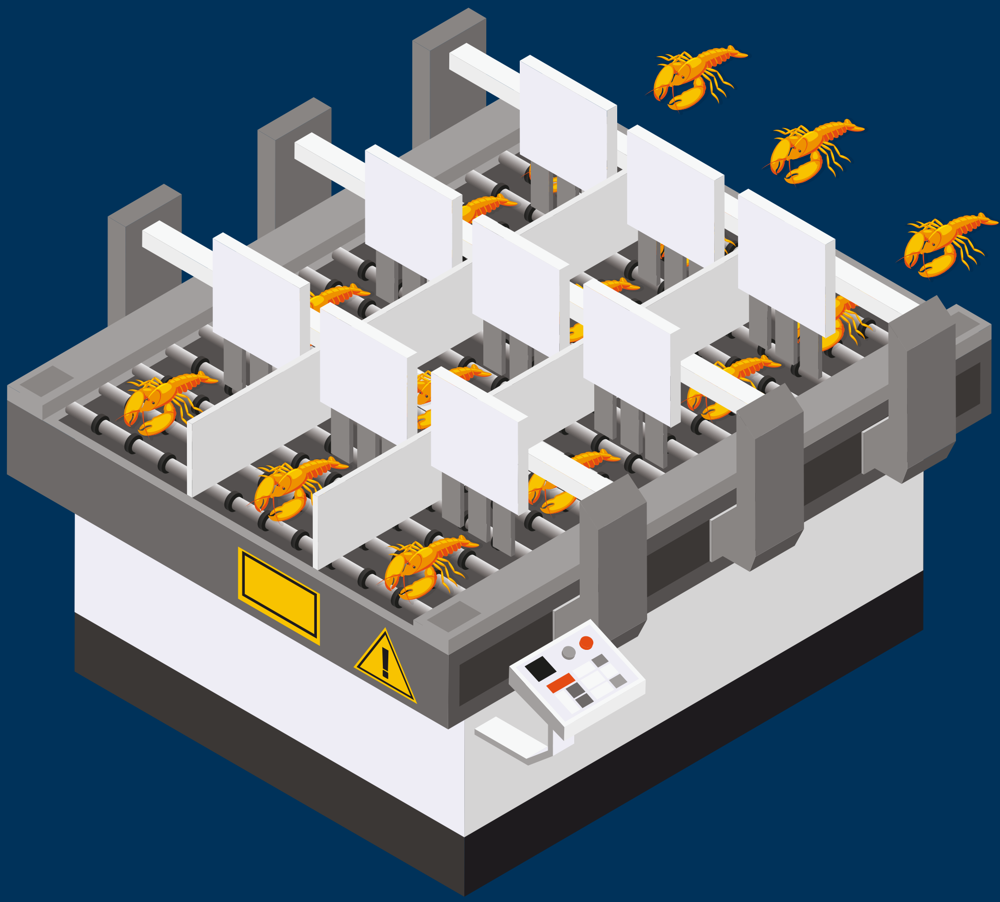
Focus on stunning

Electrical stunning

Evidence indicates that swift (within one second) and effective stunning of decapod crustaceans can be achieved when appropriate electrical parameters are applied [39,40], though other reports cite the need for longer exposure to electricity to induce and/or prolong insensibility [42].

Indications are that following electrical stunning, various forms of spontaneous activity within the central nervous system of crabs and lobsters are completely arrested, with a loss of responsiveness to all types of sensory stimulation and a failure in neuromuscular activation [191]. These findings are all consistent with the nervous system being incapacitated both centrally and peripherally, preventing all normal neuronal functioning [191]. Other information

Electrical stunning



also indicates no additional stress (as evidenced by L-lactate levels) associated with delivery of an effective electrical stun to crabs or lobsters using commercially available equipment (the 'Crustastun'), when compared with comparable handling alone [192]. However, there are some indications that animals subjected to electricity for several seconds may experience localised over-heating [41,193] with associated welfare and commercial implications, though this depends on the electrical parameters used. There is also evidence of variable responses to electrical stunning by different species [42]. These outcomes highlight the need for further refinement and improved consistency of methodology in order to reduce any welfare risks associated with electrical stunning.

Equipment design, placement of the animal in the equipment (to ensure effective current flow through the body and all limbs), and specifications for the exact electrical parameters to apply for each species to ensure swift and humane stunning would all benefit from further research. Assessment of the duration of insensibility post stun – and how to ensure this is sufficient to allow subsequent killing prior to regaining consciousness – is also needed for each species as reports vary, from minutes [41] to hours [193]. Similarly, the efficacy of currently available equipment models needs further, independent verification.

Nevertheless, overall the available information indicates that when appropriate parameters are applied, electrical stunning can deliver a swift, effective and humane stun to decapod crustaceans including crabs, lobsters, crayfish and shrimps. Hence, Crustacean Compassion considers this to be the best option currently available for rendering these animals insensible prior to swift application of an effective killing method.

It should be noted, however, that this relates to the use of electrical methods for stunning only, pending further research on electrical killing. There is mixed information on whether and how it is possible to use electrically based methods to ensure subsequent death prior to sensibility being regained.

Chilling

The wide variety of habitats and conditions in which different decapod crustacean species live, and to which they are adapted, will influence both the impact of chilling on their welfare and its speed and efficacy as a stunning (and/or killing) method. Uncertainties regarding the aversiveness of low temperatures to decapod crustaceans further compound the difficulties associated with assessing the likelihood and extent of suffering caused by chilling [27]; even temperate species (adapted to cold conditions) will avoid low temperatures within a gradient [194]. There may also be doubts as to whether chilling results in cessation of neural functions, rather than only muscular paralysis [195], at least in some species. Whilst sudden chilling may rapidly inhibit sensory neurons in certain species, the nervous system of others continues to function even at extremely low temperatures [196–198].

This variation in neurological response to extreme temperatures is seen both within, as well as between, individual species [197], further raising questions about its efficacy and humaneness as a stunning method. Other research clearly indicates negative impacts on the welfare of several species subjected to chilling. Taken together, these findings highlight both the welfare risks and the functional inadequacies of chilling as either a stunning or killing method.

Based on this information, Crustacean Compassion recommends that decapod crustaceans should not be subjected to chilling for the purposes of stunning/killing, unless and until there is robust species-specific evidence that the method can achieve distress-free insensibility and cessation of central neural activity in the species in question.

Dry/air chilling

Dry/air chilling, sometimes used with the aim of rendering large decapod crustaceans insensible prior to killing, is associated with a number of welfare concerns [27]. The time taken to reach insensibility – and hence the duration of potential suffering – varies with the species, size, metabolic state and cooling rate [199] and is compounded by the fact that this method takes longer than wet/ice chilling due to the lower rate of heat transfer in air compared with water [200]. Research shows that (temperate) crabs placed in a freezer at -37°C take 30-40 minutes to lose behavioural signs of sensibility, with subsequent placement into water at 12°C following 60 minutes in the freezer revealing irreversible damage along with autotomy, indicating stress occurred prior to death [39].

Given the evidence, Crustacean Compassion recommends that decapod crustaceans should not be subjected to dry/air chilling due to the risk of prolonged suffering associated with this method of stunning.

Wet/ice chilling

Decapod crustaceans are subjected to wet/ice chilling in a variety of circumstances and for a range or purposes. However, evidence indicates that use of wet/ice chilling as a stunning method is associated with both welfare concerns and doubts regarding its efficacy. Various studies exposing temperate crabs to chilling in iced water/slurry found them still to be responsive to stimuli after two minutes [42], 100 minutes (despite an internal temp of 1.8°C) [36] and still unaffected after 14 hours at temperatures as low as 2°C [201]. Although mild paralysis (with retention of antennal, maxilliped, and limb movement) has been seen to occur in two hours at -1.5°C, the last segments of the limbs become frozen. Recovery occurs within 45 minutes on return to 10°C, though with likely tissue damage [201]. Also, whilst loss of neural response to external stimuli has been reported following exposure of crayfish to wet chilling [42], in other research, the chilling of lobsters (in chilled seawater) or crayfish (in chilled fresh water), whilst leading to a state of stiffness, has been found to have no effect on processing of sensory information after one hour [41]. In contrast, some reports suggest that wet chilling may potentially be suitable for stunning or killing tropical species poorly adapted to cold temperatures [195,199]. Shrimps chilled in ice slurry can become neurally unresponsive to external stimuli after 30 seconds exposure [42], whilst an acute temperature change from 21°C to 5°C appears to inhibit neuronal responses in prawns [202].

Nevertheless, it is clear that instantaneous insensibility has not been demonstrated in any species, which together with the welfare concerns associated with exposure to very low temperatures, leads to the conclusion that wet/ice chilling should not be used as a stunning method for decapod crustaceans.

Chemical anaesthetics

The use of various chemicals to stun or anaesthetise decapod crustaceans results in widely varying outcomes and can be associated with significant welfare concerns. In addition, some chemicals proposed for this purpose are unsuitable for use on animals destined for human consumption and others have been found to be ineffective. Studies have shown that neither exposure of lobsters for one hour to magnesium chloride ($MgCl_2$) [41] nor placing crabs in magnesium sulphate ($MgSO_4$) for four hours [201] or potassium chloride (KCl) for 12 minutes [39] had any anaesthetic effect, though exposure to a higher concentration of KCl saw all animals lose all behavioural responses within three minutes. Exposure to clove oil solution for 50+ minutes appears to elicit insensibility without overt signs of distress [201], with a reduction in activity of primary proprioceptive neurons [203], but there are mixed reports regarding the efficacy of the fish anaesthetic AQUI-S®. Some suggest that crabs [201] and other decapod crustaceans [195] may be rendered insensible (and even killed) using the product with no apparent distress, though the process takes several minutes and detailed evidence to support these reports is lacking. In direct contrast, other research [193] found that use of the recommended commercial concentration of AQUI-S® in seawater did not induce noticeable anaesthesia in prawns after 60 minutes (unpublished data cited in Diggles & Browman, 2018) [193], resulting in numerous tail flips/escape attempts whenever the prawns were touched.

Overall, the variable, inconclusive and in some cases concerning nature of the evidence regarding the efficacy and welfare impact of chemical anaesthetics, indicates that they should not be considered for use as a stunning method for decapod crustaceans.

CO_2 gassing

Carbon dioxide (CO_2) has been shown to inhibit synaptic transmission in crayfish [204,205]. However, the animals' behavioural responses during exposure demonstrate a strongly negative response to [204] and – when offered the choice – avoidance of [206] high CO_2. Although the avoidance behaviour decreases with lower CO_2 [204,206], only high (and therefore aversive) levels of the gas lead to unresponsiveness to mechanosensory stimulation (suggesting insensibility) within a 30-minute time period [204]. Other studies show that CO_2 exposure fails to render edible crabs insensible after 12 minutes [39], while crabs placed into CO_2 infused (hypercapnic) seawater exhibit thrashing and crushing of limbs prior to apparent paralysis after 33-60 minutes [201]. Even then, although immobile, the animals are tensed and become rigid when returned to fresh seawater to recover. Some autotomy – a clear sign of stress – is also noted. In addition, exposure of lobsters to CO_2 bubbled into water induces anaesthesia after 45 minutes, but the reduction in water pH caused by the gas leads to aversive and agitated behaviour in animals before signs of anaesthesia occur [41].

Given the strong evidence indicating both the aversiveness of CO_2 and the long duration of exposure needed to achieve insensibility, Crustacean Compassion recommends that CO_2 gas should not be used as a stunning method for decapod crustaceans due to the prolonged suffering involved.

Focus on slaughter

Boiling

The killing of any live, unstunned decapod crustaceans by placing them into boiling water, or by increasing the water temperature gradually to boiling point [207], is highly likely to cause significant suffering [199]. Evidence indicates that when subjected to this practice, larger species such as crabs, lobsters and crayfish show signs indicative of prolonged and severe suffering and distress prior to death. These include vigorous struggling, thrashing and attempts to escape from the container [27,207], behaviour noted in some species even at temperatures below 25°C [201]. Crayfish placed directly into boiling water are reported to die in around 10 seconds[207] while crabs take around 2.5 minutes to lose sensibility; and up to three minutes if chilled first [39]. Whilst death may occur more swiftly in smaller species due to their size, it is probable that they will still experience some period of suffering [27].

Hence, boiling should never be used to kill decapod crustaceans, unless animals are first rendered insensible to pain and distress through: a) effective stunning that can be guaranteed to persist during the boiling process until death occurs, or b) effective stunning followed by swift destruction of all nerve ganglia prior to boiling.

Dismemberment

The common practice of systematic removal of parts of the body of decapod crustaceans until eventual death, is highly likely to result in severe suffering, sometimes prolonged for a period of several minutes [27,199,208]. However, dismemberment is a common practice of the nephrop trade where nephrops tails are manually removed at sea (known as 'tailing') for the scampi trade. The animal is then left to die. There is strong evidence indicating that the practice of manual declawing of crabs causes distress and pain. This highlights the severe negative impact on the welfare of decapod crustaceans, as a result of this practice and other forms of dismemberment. The animals central nervous systems are not destroyed by the process, and highly credible expert opinion has expressed concerns about the welfare impact of this practice [199]. This supports the conclusion that removal of body parts from any conscious decapod crustacean causes severe mental and physical suffering until death eventually ensues.

This information underpins the conclusion that dismemberment of live conscious decapod crustaceans is completely unacceptable on welfare grounds and should never be undertaken.

Electrical killing

There are significant uncertainties regarding whether electrical killing of decapod crustaceans can be achieved without potentially prolonged suffering. Whilst there is sound evidence that a swift and effective stun can be achieved when appropriate electrical parameters are applied [39,40,191], there are mixed reports regarding whether and how it is possible to use electricity to ensure subsequent death prior to sensibility being regained. Industry-based accounts suggest that both stunning (within one second) and death of crabs (within 10 seconds) and lobsters (within five seconds) can be achieved using commercially available electrical equipment such as the 'Crustastun' [209]. This is supported by reports suggesting that neither crabs nor lobsters recover following 10 seconds exposure to electricity [192]. However, in direct contrast, peer reviewed work and expert opinion indicate that crabs, whilst effectively stunned, may remain alive following prolonged exposure (two minutes) to electricity as a second stun after an initial stun [39]. Subsequent recovery of crabs exposed to several seconds of electricity [40] in other studies further supports these findings. Moreover, the manufacturers of another commercially available electrical stunning device (the 'Stansas') recommend swift killing (through other methods) following electrical stunning to ensure humane death [210]. There is also a significant lack of clarity regarding the required parameters needed to ensure stunning and killing of different species/sizes of animal.

Pending further evidence-based, consistent, independent information regarding the welfare implications of, and appropriate technical specifications for achieving electrical killing, Crustacean Compassion advocates that electrical methods cannot be recommended for killing decapod crustaceans.

High-pressure processing

The welfare implications of High-pressure processing (HPP) have yet to be effectively investigated. Unsubstantiated industry reports suggest it can lead to relatively swift (within six seconds) – though not instantaneous – insensibility prior to subsequent death for large decapod crustaceans [211] due to the high pressure inhibiting the neurological mechanisms associated with pain response [212]. In addition, research investigating the impact of modest pressure on lobster nerve function found changes in synaptic transmission (nerve signalling mechanisms) [213,214], suggesting HPP may have future potential for use as a humane method of stunning/killing. However, species-specific scientific studies of HPP *per se* are absent.

There are also concerns that the overall process may involve aversive practices pre-death, including high stocking density within the chamber, exposure to fresh water (with associated osmotic shock) and exposure to gradually increasing pressure (with associated barometric shock) prior to insensibility/death. There is also a lack of documented information regarding the duration of consciousness and concurrent impact on welfare under these conditions. In view of these uncertainties, further robust information is needed before confident conclusions can be drawn about whether this killing method is acceptable from a welfare perspective.

> Until further objective evidence is forthcoming, Crustacean Compassion believes HPP cannot be safely recommended as a humane killing method for decapod crustaceans, unless they are first effectively stunned and remain insensible until death occurs.

Spiking or splitting

Skilled, competent application of certain methods of mechanical killing of large decapod crustaceans that effectively destroy all ganglia can result in relatively swift (though usually not instantaneous) death. Such methods include the 'spiking' of crabs or 'splitting' of lobsters and similarly shaped species. However, due to the need for – and skill required to achieve – highly accurate, speedy positioning and execution of the spiking/splitting, these methods are also associated with high risk of severe suffering unless undertaken skilfully and swiftly [27,195,200]. As a result, these practices should only be applied where practitioners are highly trained and able to demonstrate consistent competency in the techniques [27,195,200]. Spiking/splitting are also unlikely to be suitable for killing large numbers at one time due to the likelihood of operator fatigue and associated reduction in the accuracy of implementation needed to ensure humaneness. For example, it is essential that both nerve centres (ganglia) in crabs are destroyed simultaneously to avoid pain and distress [215] and ensure death [169]. The non-centralised positioning of ganglia in decapod crustaceans and the associated difficulties in achieving simultaneous destruction of all ganglia through these mechanical methods, means that the overall process may potentially take up to 10 -15 seconds to complete [195,216].

In summary, spiking/splitting methods should only be applied by trained, competent practitioners, immediately after the animals have first been effectively electrically stunned.

In such circumstances, recommended methods involve [200]:

- The 'spiking' of crabs such that their two main nerve centres are rapidly destroyed by spiking both ganglia from the underside of the animal.
- The 'splitting' of lobsters and similarly shaped species, such that effective and swift destruction is achieved of both of the nerve centres running down their central length (ventral longitudinal midline). This should be undertaken by cutting along the midline on the underside of the animal and spiking the first nerve centre (the supra-oesophageal ganglion) via the appropriate point through the head.

Chilling

Wet/ice chilling

There is clear evidence indicating both the ineffectiveness and negative welfare impact of wet/ice chilling as a method of killing decapod crustaceans [27]. Prolonged exposure to ice fails to elicit even insensibility in various temperate species. In contrast, some reports suggest that chilling in ice slurry might be suitable for killing tropical species that are more susceptible to low temperatures [195,199]. Unpublished observations cited in Diggles & Browman (2018) [193] report that ice slurry is effective for sedating or euthanizing large mud crabs and that submergence in ice slurry for at least one minute is an effective (and commonplace) way to kill large tropical prawns [193]. However, whilst tropical prawns subjected to a rapid fall in temperature (from 21°C to 5°C) are reported to die within two hours [202], other reports cite the ability of shrimps to recover when moved to warm water following exposure to ice slurry for five minutes, during which signs of stress are displayed. Similarly, research placing crabs and crayfish in ice slurry for five minutes failed to kill any of the animals, which subsequently fully recovered following removal from the slurry [42]. The risk of osmotic shock associated with exposing marine species to freshwater ice slurry [195], or exposure for extended periods prior to insensibility in saline solutions into which freshwater ice melts (thereby reducing salinity) are additional concerns [27].

Overall, the evidence indicates that wet/ice chilling should not be used as a killing method for decapod crustaceans, being largely ineffective for temperate species, associated with serious risk to welfare for all species, and failing to deliver instantaneous insensibility or death to any species.

Dry/air chilling

There is little credible evidence available regarding the efficacy of dry/air chilling as a method of killing decapod crustaceans. However, the likely extended duration of exposure until insensibility compared with wet/ice chilling (due to lower rate of heat transfer in air vs water) [200] adds further to the welfare concerns associated with chilling in ice. In addition, research shows that dry chilling in a freezer takes 30-40 minutes to elicit insensibility in temperate crabs [39]. The animals also subsequently display signs of stress (autotomy) when removed from the cold after 60 minutes. These outcomes strongly demonstrate both the extended duration and the level of suffering endured before death occurs.

In the light of the lack of evidence of efficacy, and the evidence of its negative and prolonged welfare impact, dry chilling should not be used as a killing method for decapod crustaceans.

Fresh water ‘drowning’ (marine species)

Killing of marine decapod crustaceans by placing them in fresh water (sometimes described as fresh water ‘drowning’) is widely considered to be unacceptable from a welfare perspective [39,130,195,199,201]. This practice, which leads to death through severe osmotic shock, has been shown to result in aversive behaviour [201,217] and is very likely to cause pain and distress [199]. Marine crabs placed in fresh water become immediately motionless and rigid for 10 minutes, but this is followed by high activity and autotomy, indicating stress/distress. They also tear at their abdomens and walking legs and take three to five hours to die [201].

In view of the evidence, freshwater drowning of marine decapod crustaceans should not be undertaken due to the serious and prolonged suffering it causes.

High salt solution

The use of high salt solution to kill decapod crustaceans results in behaviours indicative of stress and distress, with apparently prolonged consciousness for several minutes [39,217]. Although crabs appear unaffected after four hours in a magnesium sulphate solution ($MgSO_4$) [201], research placing crabs into sodium chloride (NaCl) solution for 10 minutes leads to display of abnormal behaviours, including immediate retraction of antenna followed by stillness and then feeble walking [217]. Whilst spontaneous behaviour ceases within 10 minutes, autotomy occurs during subsequent boiling, indicating stress and hence continuing sensory ability [217].

Similarly, crabs placed in NaCl and a low concentration of KCl display aversive behaviour, vigorously trying to escape, and are still conscious after three minutes (as indicated by behavioural responses to touching and handling). Crabs exposed to a higher concentration of KCl do not try to escape but still take over one minute to lose all behavioural responses [39]. These findings suggest that although placing crabs in certain high salt solutions will eventually kill the animals, it is likely that the death will be slow and preceded by a period of suffering. Studies involving other species are lacking though and given the widely different habitats/environments and their variable abilities to adapt to different salinities, it is likely that different species will respond differently to exposure to high salt solutions [218].

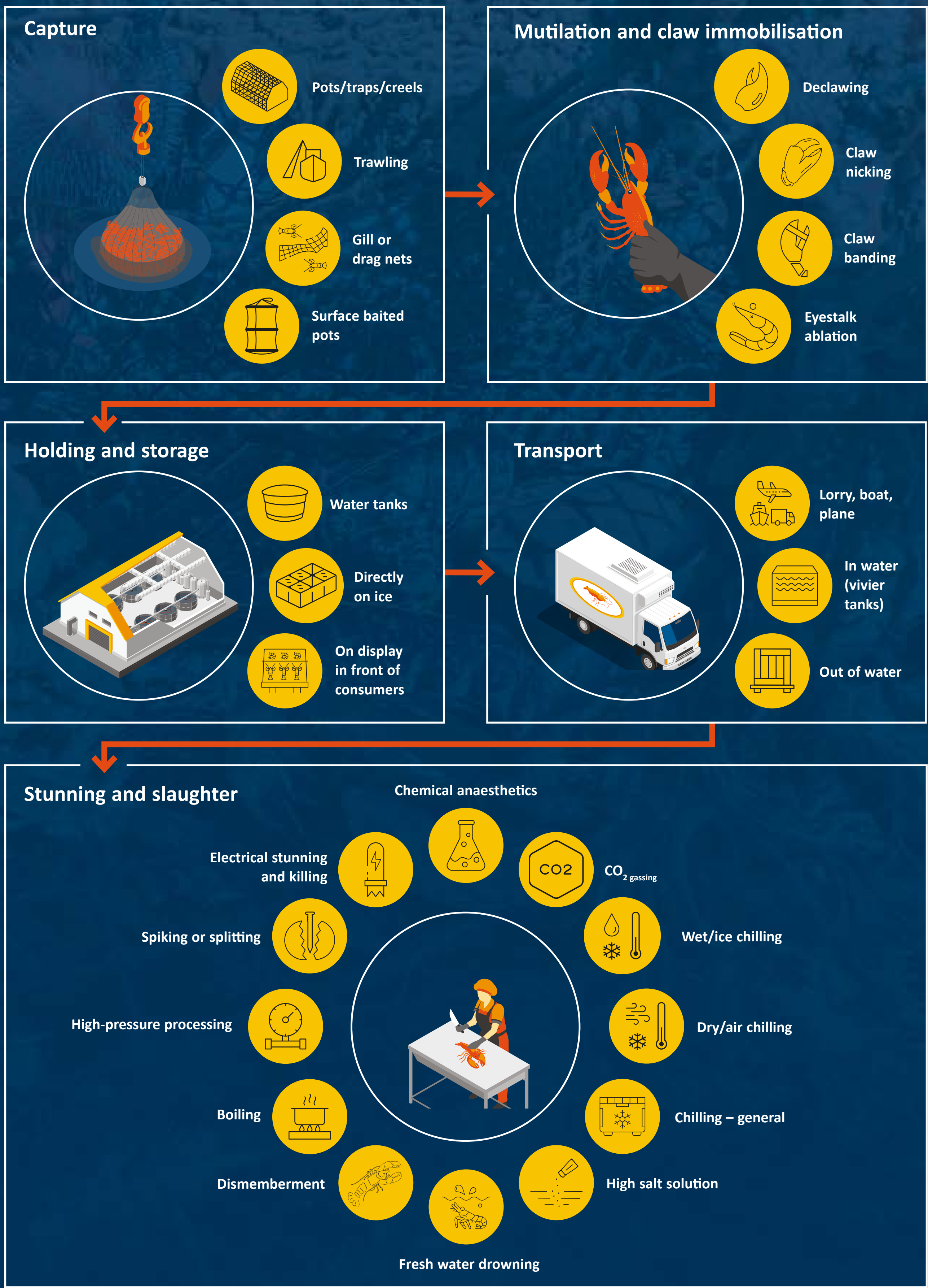
> However, in the absence of detailed species-specific research, available evidence indicates that use of high salt solutions as a killing method for decapod crustaceans is unacceptable, due both to the level and to the duration of suffering endured prior to insensibility/death.

CO_2 gassing

The response of decapod crustaceans to carbon dioxide (CO_2) clearly indicates that levels of the gas high enough to bring about insensibility and death are very aversive to the animals. For example, research placing crayfish into varying levels of CO_2 [204] found that high levels lead to avoidance behaviours indicating a strongly repellent effect of the gas. No avoidance is seen with low levels of CO_2, but only at high levels is unresponsiveness (to mechanosensory stimuli) seen, taking up to 30 minutes to develop. Monitoring of heart and ventilatory rates show a complete cessation (i.e. an indication of death) within the same time period, but again only at high (aversive) CO_2 levels. Similarly, placing crabs into CO_2 infused (hypercapnic) seawater has been shown to result in the animals thrashing and crushing limbs prior to apparent paralysis after 33-60 minutes [201]. Even then, although immobile, the animals are tensed and become rigid when returned to fresh seawater to recover. Some autotomy – a sign of stress – is also noted. Other work has also demonstrated a failure to elicit unconsciousness in crabs despite prolonged exposure (12 minutes) to CO_2 [39].

> This evidence highlights the welfare concerns associated with exposure of decapod crustaceans to CO_2 and supports the conclusion that its use as a stunning/ killing method for these species is unacceptable.

Journey map


Capture
Pots/traps/creels
Trawling
Gill or drag nets
Surface baited pots
Mutilation and claw immobilisation
Declawing
Claw nicking
Claw banding
Eyestalk ablation
Holding and storage
Water tanks
Directly on ice
On display in front of consumers
Transport
Lorry, boat, plane
In water (vivier tanks)
Out of water
Stunning and slaughter
Chemical anaesthetics
CO2
CO_2 gassing
Electrical stunning and killing
Spiking or splitting
Wet/ice chilling
High-pressure processing
Dry/air chilling
Boiling
Chilling – general
Dismemberment
High salt solution
Fresh water drowning

Capture recommendations

Overall: Capture and post-capture practices must be adapted, on a species-specific basis, to reduce to a minimum the impact on the welfare of decapod crustaceans. This includes both the target animals and those unintentionally affected during the processes.

Practice	Recommendation
General	The many, often severe challenges faced by decapod crustaceans during capture or harvesting and subsequent processes are the cause of very significant welfare issues. These are suffered both at the time and also in the longer term, having an impact on the welfare and survival during onward travel and storage. Crustacean Compassion wants to see the least harmful methods of capture and post-capture handling and holding applied for each species, an approach that would be of benefit both commercially and most importantly, to the animals. Equipment and practices that reduce levels of and impact on bycatch of non-target decapod crustaceans and other species should also be used.
Trawling	In summary, a compelling body of evidence indicates that use of trawling as a capture method for decapod crustaceans has very significant and wide-ranging negative impacts on both their short and long term welfare and survival, as well as affecting non-target aquatic animals. Crustacean Compassion would therefore urge that plans are developed to move away from trawling in favor of alternative, less harmful, capture methods. Whilst trawling continues some of the challenges posed to the animals could be reduced to some extent through adapting equipment, fishing and handling practices during and immediately following capture. Crustacean Compassion therefore urges that available information on how to reduce impact should be applied in practice at each stage of capture and on-board treatment. Such an approach is likely to improve the welfare and survivability of target and bycatch decapod crustaceans and as a consequence, to bring associated commercial benefits.
Trapping	Overall, multiple factors influence the welfare and survival of pot-caught decapod crustaceans. Crustacean Compassion believes that ensuring species-appropriate practices that minimise negative impact on welfare during all these procedures is essential at each stage. This includes optimising design of pots/traps to reduce injury, minimising hauling depth and rate, and applying considerate handling and treatment during and immediately after removal from the traps on deck. Changes to current practices and pot design to reduce the risk of pot loss and of associated deaths through 'ghost fishing', together with systematic retrieval of missing pots, should also be undertaken.

Capture recommendations (continued)

Practice	Recommendation
Bycatch (decapod crustaceans)	There is a wealth of evidence indicating that sometimes high levels of bycatch can be associated with decapod crustacean fishing, including undersized individuals of the target species and other non-target species of decapod crustacean. Even when returned to the sea alive, many unintentionally caught animals suffer morbidity and mortality as a result of the stressors experienced during the catching and sorting processes. Crustacean Compassion wants to see changes to fishing practices and equipment, including the design and materials used for nets and pots, to facilitate a reduction in the level of bycatch. Refinement – and reduced duration – of on-board handling and sorting practices should also be undertaken to help improve the ability of discarded bycatch to survive and thrive on return to the sea.
Post-capture handling	In summary, the many stressors to which decapod crustaceans are subjected immediately following capture at sea lead to multiple welfare impacts both at the time and longer term. The available evidence-based, species-specific information, indicating which practices could be modified and refined in order to reduce the level of negative impact, needs to be reviewed and implemented in practice at each stage post-capture. Overall, handling processes should be undertaken with care and the frequency and duration minimised, alongside protection of the animals from exposure to inappropriate environmental parameters during handling, sorting and transfer to holding containers. Refresher training of crew to ensure transfer and implementation of the latest knowledge in this area could also be beneficial.
On-board holding/storage	Overall, it is clear that the nature of the various on-board holding conditions in which decapod crustaceans that remain alive post capture are stored, can have a highly significant impact on many welfare parameters and on the animals' ability to survive longer term during subsequent transport and storage. Species-specific information on appropriate holding conditions, that take account of each species' physical, physiological and behavioural needs, should be understood and applied in practice.

Holding and storage recommendations

Overall: In order to reduce the suffering experienced by decapod crustaceans during holding/storage, the conditions must be optimised to meet species-specific needs, and the duration and frequency of periods of storage, must be minimised.

Practice	Recommendation
General	All holding and storage methods and facilities should be adapted and maintained to ensure they effectively meet the biological and behavioural needs of the species in question. The clear evidence of serious suffering and mortality caused by unsuitable holding methods and storage facilities also illustrate the need to reduce the duration of storage to a minimum. Urgent review and adjustment of logistics and marketing practices to facilitate these improvements is also recommended. In some cases, where negative welfare impact is difficult to overcome or certain practices – such as live displays – are unnecessary, live decapod crustaceans should not be held/stored at all.
Pre-transport holding	See: Pre-transport holding and purging in the Transport section.
Air exposure/emersion	The many negative consequences for decapod crustaceans associated with air exposure during holding/storage highlight the need to reduce emersion to a minimum. The frequency and duration of emersion of decapod crustaceans throughout the capture/harvest to killing process must be kept to an absolute minimum, be replaced with in-water holding methods when involving longer periods of storage, provide optimal conditions (temperature, humidity) when undertaken and be avoided completely whenever possible.
Water quality	Given the serious and wide-ranging negative effects on welfare of poor water quality during holding/storage of decapod crustaceans, all holding/storage facilities should, as a basic minimum requirement, ensure that levels of dissolved oxygen and other key parameters are maintained at species-appropriate levels throughout the storage period. Water quality must be assessed at least daily and necessary adjustments to management and equipment made accordingly.
Light exposure and lack of shelter	The clear preference of many decapod crustacean species to avoid light and seek shelter should be taken into account when designing, developing and managing holding and storage systems. The short and sometimes long- lasting harm to welfare associated with both exposure to bright light and the failure to provide opportunities to shelter/hide, add to other stressors experienced during the storage period, contributing to poor welfare, morbidity and mortality.

Holding and storage recommendations (continued)

Practice	Recommendation
Temperature	It is clear that both temperature levels and fluctuations have a highly significant impact on the welfare and survival of decapod crustaceans during holding and storage, both alone and in combination with other environmental conditions. During storage, maintenance of temperature ranges to which the various species are adapted, and slow acclimatisation when changes are required (for example, after chilling during transport) is therefore essential to reduce stress, morbidity and mortality at this time. This should be facilitated through ensuring knowledge of species-specific needs, and frequent monitoring and management of temperature in all holding and storage situations.
Stocking density	The clear evidence of the negative impact on welfare of high stocking densities during holding and storage of decapod crustaceans indicates the need to ensure that adequate species-specific space allowances are provided during containment. There should be sufficient space to allow the animals room to move away from others to avoid antagonistic interactions, and to enable water quality to be maintained at appropriate levels. Optimum species-specific stocking densities that enable expression of natural behaviour and avoidance of negative welfare impacts currently seen in overcrowded holding conditions, should be established and implemented in practice, particularly when storage is of long duration.
Mixing species	The practice of mixing different species of decapod crustacean with each other and/or with other aquatic animals causes significant stress. It should therefore be avoided at all times, and each individual species should be kept apart from others during holding/storage, regardless of duration.
Holding duration with/without food	In summary, evidence clearly indicates that during storage of live decapod crustaceans, the risks to welfare increase with duration of holding, especially in the absence of feeding. Any storage of these animals should, therefore, be kept to the minimum necessary. Long periods of holding should be avoided and the conditions to which the animals are exposed needs to optimised.

Transport recommendations

Overall: The occurrence, frequency and duration of transportation of live decapod crustaceans must be minimised. Travelling conditions must be adapted to the species to optimise welfare, and approaches that replace live transport with a carcass-only trade developed and implemented.

Practice	Recommendation
Overall transport process	Given the large body of robust evidence of the harm caused to decapod crustaceans in transit, there is an urgent need for many current transport practices to be modified. They should be better tailored to species-specific needs in order to reduce the currently large scale, severe negative impact on the welfare of these animals. Any knowledge gaps relating to species-appropriate conditions need to be urgently addressed through undertaking further studies and applying the findings in practice. The various welfare challenges posed by current practices, along with recommendations for change, are outlined in detail in the issue-specific Position Statements. Alongside improvements to transport practices, there is a need to review whether all current movements of live decapod crustaceans are necessary. Further development of transport methods and adaptation of logistics to enable successful transportation of these animals post- rather than pre-slaughter, should also be prioritised.
Pre-transport holding and purging	The overall impact of the conditions experienced pre-transport on the welfare and survival of decapod crustaceans during subsequent transportation is very clear. This highlights the critical importance of taking a properly evidence-based approach to understanding and applying the most appropriate species-specific practices in the period between capture and transport. This is not only positive for animal welfare but also has commercial benefits. As a general rule, immersion pre-transport is recommended. However, purging, especially for prolonged periods, can lead to welfare concerns, though may be advisable on balance if transport containers lack effective water flow systems that remove nitrogenous waste in transit. Nevertheless, it is important to note that purging is only necessary in order to compensate for inadequacies in transport conditions and practices and would not be needed if holding facilities in transit were improved. Where knowledge gaps exist, (e.g. optimal transport conditions and systems capable of removing sufficient quantities of nitrogenous waste for the duration of journeys), these should be urgently addressed through focused research and development and swift application of learnings in practice.
Air exposure/emersion	Overall, there is a wealth of scientific evidence to show that exposing decapod crustaceans to air during transport (and in other situations) is frequently associated with serious acute and chronic welfare problems, often resulting in mortality. Some of the most serious impacts could be mitigated to some extent, and for some species, by optimising environmental conditions to better meet species-specific needs, and by avoidance of disturbance. Hence, only with very strictly controlled conditions in which temperature, humidity, containment method etc. are optimised throughout travel for the species involved, should emersion in transit be undertaken. However, even then, if meaningful reduction in suffering and death is to be achieved, the duration of any period of air exposure must be minimised for all species and for some, such as shrimp/prawns, emersion in transit should be avoided completely.

Transport recommendations (continued)

Practice	Recommendation
In-water/immersed transport	In summary, providing and maintaining species-specific water quality, salinity and temperature ranges during transport of decapod crustaceans in water is crucial to their welfare and survival. It should be mandatory to ensure that existing knowledge of the biological needs of each transported species is applied when developing and using equipment and on-board operating systems. They should be demonstrably capable of providing, monitoring and maintaining throughout transportation the most suitable water quality and environmental parameters for the species.
Temperature	In summary, a significant body of evidence exists to demonstrate the critical importance to decapod crustacean welfare and survival of identifying, applying and maintaining species-appropriate temperatures throughout the transport process. This is the case for all species and regardless of the mode and duration of transport. Existing scientific knowledge should be more effectively utilised and where necessary, current transport practices and equipment adapted to ensure monitoring and maintenance of appropriate temperatures in transit. Such an outcome would be of benefit both to the animals and commercially.
Duration and complexity of journeys	Given the clear correlation between journey duration/complexity, and the risk and severity of impact on animal welfare, any live transportation of decapod crustaceans should be planned and implemented to ensure the minimum possible journey times (including loading and unloading times). Journeys should also follow the most direct, least complex routes possible between dispatch sites and destinations.
Containment methods	The exact nature of the containment methods and associated parameters during transport clearly have important implications for the welfare of decapod crustaceans. Any such practices that expose animals to physical, physiological and behavioural challenges, such as high stocking density, should be avoided or modified to take account of species-specific characteristics and needs in order to reduce the negative impact on welfare.
Packaging	In summary, there is a clear need to ensure species-specific suitability of transport packaging methods. This includes their ability to maintain appropriate environmental conditions such as humidity/moisture and temperature, and ensure avoidance of risks to welfare, such as those posed by deterioration of the materials in transit. Robust evidence is currently limited regarding the most suitable packaging materials and methods to use in order to protect decapod crustacean welfare during transport. Further strengthening of knowledge about the impact on welfare of different transport packing methods, and swift application of learnings in practice to ensure better protection of animal welfare is recommended.

Transport recommendations (continued)

Practice	Recommendation
Exposure to light and lack of shelter	The clear preference of many decapod crustacean species to avoid light and seek shelter should be taken into account in designing/developing and implementing pre, peri and post transport systems and processes. The short term and sometimes long lasting harm to welfare associated with both exposure to bright light and the failure to provide opportunities to shelter/hide add to other stressors experienced in transit. This contributes to poor welfare and hence, potentially increasing morbidity and mortality throughout the transport process.
Physical disturbance	In summary, studies focused on assessing the impact of physical disturbances – including vibrations/shaking, noise and vigorous handling – on the welfare of decapod crustaceans in transit confirm that they pose a significant additional stressor in themselves, and can also worsen the negative effects of other stressors experienced during transport. Transport practices should be adapted to mitigate against physical trauma (e.g. road vibrations) and ensure reduction/avoidance of noise exposure on all journeys involving live decapod crustaceans in order to improve welfare and survival.

Mutilations and claw immobilisation recommendations

Overall: decapod crustaceans should not be subjected to any mutilation for any purpose. The only exception to this would be when the procedure is undertaken by a veterinary surgeon for direct benefit to the welfare of the individual.

Practice	Recommendation
Declawing	Crustacean Compassion recommends that neither the practice of manually removing one or both claws from live crabs or other decapod crustaceans post harvest, nor subsequently returning them to the ocean, should be permitted.
Claw nicking	Given the welfare harms caused by claw immobilisation, the use of handling, storage and transport practices that avoid the need to restrict claw use in decapod crustaceans should be promoted. Due to the clear evidence of its negative impact on welfare, claw nicking should be prohibited and where essential for the avoidance of injuries to the animals, claw banding could be used instead.
Claw banding	Claw banding results in restriction of natural movement and behaviour with associated stress for the animals, so banding should not be used for prolonged periods of storage. More welfare-friendly alternative approaches to avoiding welfare problems associated with fighting and injury between captive decapod crustaceans should be developed and applied in practice.
Eyestalk ablation	Crustacean Compassion recommends that eyestalk ablation of any decapod crustacean for any purpose is unacceptable and should be prohibited. Consideration could be given to applying alternative approaches to increasing fecundity, where these are humane.

Stunning & slaughter recommendations

Overall: Decapod crustaceans should only be stunned using methods that result in instantaneous* insensibility to pain and distress or where insensibility is induced without causing pain and distress. This insensible state must be maintained until death occurs. In addition, decapod crustaceans should only be slaughtered/killed using methods that result in either instantaneous* death or instantaneous* insensibility to pain and distress until death occurs.

	Stunning	Slaughter / Killing
Electrical stunning and electrical killing	The available information indicates that when appropriate parameters are applied, electrical stunning can deliver a swift, effective and humane stun to decapod crustaceans including crabs, lobsters, crayfish and shrimp. Hence, Crustacean Compassion considers this to be the best option currently available for rendering these animals insensible prior to swift application of an effective killing method.	Pending further evidence-based, consistent, independent information regarding the welfare implications of, and appropriate technical specifications for achieving electrical killing, Crustacean Compassion believes that electrical methods cannot be recommended for killing decapod crustaceans.
Spiking or splitting	*Not a method of stunning*	Spiking/splitting methods should only be applied by trained, competent practitioners, immediately after the animals have first been effectively electrically stunned.
High-pressure processing	*Not a method of stunning*	Until further objective evidence is forthcoming, HPP cannot be safely recommended as a humane killing method for decapod crustaceans, unless they are first effectively stunned and remain insensible until death occurs.
Boiling	*Not a method of stunning*	Boiling should never be used to kill decapod crustaceans, unless animals are first rendered insensible to pain and distress through: a) effective stunning that can be guaranteed to persist during the boiling process until death occurs, or b) effective stunning followed by swift destruction of all nerve ganglia prior to boiling.

*within one second

Stunning & slaughter recommendations (continued)

	Stunning	Slaughter / Killing
Dismemberment	*Not a method of stunning*	Dismemberment of live conscious decapod crustaceans is completely unacceptable on welfare grounds and should never be undertaken.
Fresh water 'drowning' (marine species)	*Not a method of stunning*	Freshwater drowning of marine decapod crustaceans should not be undertaken due to the serious and prolonged suffering it causes.
High salt solution	*Not a method of stunning*	In the absence of detailed species-specific research, available evidence indicates that use of high salt solutions as a killing method for decapod crustaceans is unacceptable, due both to the level and to the duration of suffering endured prior to insensibility/death.
Chilling – general	Decapod crustaceans should not be subjected to chilling for the purposes of stunning/killing, unless and until there is robust species-specific evidence that the method can achieve distress-free insensibility and cessation of central neural activity in the species in question.	Decapod crustaceans should not be subjected to chilling for the purposes of stunning/killing, unless and until there is robust species-specific evidence that the method can achieve distress-free insensibility and cessation of central neural activity in the species in question.
Dry/air chilling	Decapod crustaceans should not be subjected to dry/air chilling due to the risk of prolonged suffering associated with this method of stunning.	In the light of the lack of evidence of efficacy, and the evidence of its negative and prolonged welfare impact, dry chilling should not be used as a killing method for decapod crustaceans.

Stunning & slaughter recommendations (continued)

	Stunning	Slaughter / Killing
Wet/ice chilling	Instantaneous insensibility has not been demonstrated in any species, which together with the welfare concerns associated with exposure to very low temperatures, leads to the conclusion that wet/ice chilling should not be used as a stunning method for decapod crustaceans.	Overall, the evidence indicates that wet/ice chilling should not be used as a killing method for decapod crustaceans, being largely ineffective for temperate species, associated with serious risk to welfare for all species, and failing to deliver instantaneous insensibility or death to any species.
CO_2 gassing	Given the strong evidence indicating both the aversiveness of CO_2 and the long duration of exposure needed to achieve insensibility, CO_2 gas should not be used as a stunning method for decapod crustaceans due to the prolonged suffering involved.	Evidence highlights the welfare concerns associated with exposure of decapod crustaceans to CO_2 and supports the conclusion that its use as a stunning/ killing method for these species is unacceptable.
Chemical anaesthetics	Overall, the variable, inconclusive and in some cases concerning nature of the evidence regarding the efficacy and welfare impact of chemical anaesthetics, indicates that they should not be considered for use as a stunning method for decapod crustaceans.	Chemical anaesthetics should not be used as a killing method for decapod crustaceans.

References

1. Crustacean Compassion *Scale of Impact: Prawn/Shrimp Imports*; 2021;

2. Crustacean Compassion *Scale of Impact: Number of Animals*; 2020;

3. Legislation.gov.uk Animal Welfare (Sentience) Act 2022 Available online: https://www.legislation.gov.uk/ukpga/2022/22/contents (accessed on 13 March 2023).

4. Birch, J., Burn, C., Schnell, A., Browning, H., & Crump, A., 2021. Review of the evidence of sentience in cephalopod molluscs and decapod crustaceans. Department of Philosophy, Logic and Scientific Method, London School of Economics and Political Science. Commissioned and funded by Defra. https://www.lse.ac.uk/business/consulting/assets/documents/Sentience-in-Cephalopod-Molluscs-and-Decapod-Crustaceans-Final-Report-November-2021.pdf

5. Lancaster, J.; Frid, C.L.J. The Fate of Discarded Juvenile Brown Shrimps (Crangon Crangon) in the Solway Firth UK Fishery. *Fish Res* **2002**, *58*, doi:10.1016/S0165-7836(01)00357-5.

6. Milligan, R.J.; Albalat, A.; Atkinson, R.J.A.; Neil, D.M. The Effects of Trawling on the Physical Condition of the Norway Lobster Nephrops Norvegicus in Relation to Seasonal Cycles in the Clyde Sea Area. *ICES Journal of Marine Science* **2009**, *66*, doi:10.1093/icesjms/fsp018.

7. Harris, R.R.; Ulmestrand, M. Discarding Norway Lobster (Nephrops Norvegicus L.) through Low Salinity Layers – Mortality and Damage Seen in Simulation Experiments. *ICES Journal of Marine Science* 2004, *61*, doi:10.1016/j.icesjms.2003.08.002.

8. Raicevich, S.; Giomi, F.; Pranovi, F.; Giovanardi, O.; Di Muro, P.; Beltramini, M. Onset of and Recovery from Physiological Stress in Liocarcinus Depurator after Trawling and Air Exposure under Different Seasonal Conditions. *Hydrobiologia* 2011, *664*, doi:10.1007/s10750-010-0590-3.

9. Albalat, A.; Gornik, S.G.; Atkinson, R.J.A.; Coombs, G.H.; Neil, D.M. Effect of Capture Method on the Physiology and Nucleotide Breakdown Products in the Norway Lobster (Nephrops Norvegicus). *Marine Biology Research* 2009, *5*, doi:10.1080/17451000802603637.

10. Revill, A. Survival of Discarded Fish: A Rapid Review of Studies on Discard Survival Rates. *European commission, directorate general for maritime affairs and fisheries Policy development and co-ordination* 2012.

11. Newland, P.L.; Neil, D.M.; Chapman, C.J. Escape Swimming in the Norway Lobster. *Journal of Crustacean Biology* 1992, *12*, doi:10.2307/1549027.

12. Gornik, S.; Albalat, A.; Atkinson, R.; Coombs, G.; Neil, D. The Influence of Defined Ante-Mortem Stressors on the Early Post-Mortem Biochemical Processes in the Abdominal Muscle of the Norway Lobster, Nephrops Norvegicus (Linnaeus, 1758). *Marine Biology Research* 2010, *6*, 223–238.

13. Evans, L.; Jussila, J.; Tsvetnenko, E.; McBride, S.; Fotedar, S.; Rubzen, F.; Barnes, A.; Jago, J.; Dunstan, R.; Jones, B. Physiological Studies on Stress and Morbidity During Post-Harvest Handling and Storage of Western Rock Lobster Panulirus Cygnus. II. *Standard Autopsy Techniques and Immune System Competency* 2002.

14. Basti, D.; Bricknell, I.; Hoyt, K.; Chang, E.S.; Halteman, W.; Bouchard, D. Factors Affecting Post-Capture Survivability of Lobster Homarus Americanus. *Dis Aquat Organ* 2010, *90*, doi:10.3354/dao02205.

15. Fotedar, S.; Evans, L.; Jones, B. Effect of Holding Duration on the Immune System of Western Rock Lobster, Panulirus Cygnus. *Comparative Biochemistry and Physiology – A Molecular and Integrative Physiology* 2006, *143*, doi:10.1016/j.cbpa.2006.01.010.

16. Hunter, D.A.; Uglow, R.F. Handling-Induced Changes in Haemolymph Ammonia Concentration and Ammonia Excretion Rate of Crangon Crangon (L.). *Ophelia* 1993, *38*, doi:10.1080/00785326.1993.10429895.

17. Lund, H.S.; Wang, T.; Chang, E.S.; Pedersen, L.F.; Taylor, E.W.; Pedersen, P.B.; McKenzie, D.J. Recovery by the Norway Lobster Nephrops Norvegicus (L.) from the Physiological Stresses of Trawling: Influence of Season and Live-Storage Position. *J Exp Mar Biol Ecol* 2009, *373*, doi:10.1016/j.jembe.2009.04.004.

18. Larssen, W.E.; Dyb, J.E.; Woll, A.; Kennedy, J. Factors That Affect Vitality of Northern Shrimp (Pandalus Borealis, Krøyer 1838) during Capture and Storage That Are Destined for Live Trade. *J Shellfish Res* 2013, *32*, doi:10.2983/035.032.0324.

19. Lavallée, J.; Spangler, E.S.; Hammelli, K.L.; Dohoo, I.R.; Cawthorn, R.J. Analytical Assessment of Handling, Fishing Practices, and Transportation Risk Factors on Lobster (Homarus Americanus) Health in Prince Edward Island, Canada. *J Shellfish Res* 2000, *19*.

20. Esposito, G.; Nucera, D.; Meloni, D. Retail Stores Policies for Marketing of Lobsters in Sardinia (Italy) as Influenced by Different Practices Related to Animal Welfare and Product Quality. *Foods* 2018, *7*, doi:10.3390/foods7070103.

21. D’Agaro, E.; Sabbioni, V.; Messina, M.; Tibaldi, E.; Bongiorno, T.; Tulli, F.; Lippe, G.; Fabbro, A.; Stecchini, M. Effect of Confinement and Starvation on Stress Parameters in the (Homarus Americanus). *Ital J Anim Sci* 2014, *13*, doi:10.4081/ijas.2014.3530.

22. Siikavuopio, S.I.; Johansson, G.S.; James, P.; Lorentzen, G. Effect of Starvation on the Survival, Injury, and Weight of Adult Snow Crab, Chionoecetes Opilio. *Aquac Res* 2019, *50*, doi:10.1111/are.13926.

23. Jussila, J.; Fotedar, R.; Edsman, L. Post-Harvest Handling of Freshwater Crayfish: Techniques, Challenges and Opportunities. In *Postharvest Handling*; 2017.

24. Albalat, A.; Johnson, L.; Coates, C.J.; Dykes, G.C.; Hitte, F.; Morro, B.; Dick, J.; Todd, K.; Neil, D.M. The Effect of Temperature on the Physiological Condition and Immune-Capacity of European Lobsters (Homarus Gammarus) During Long-Term Starvation. *Front Mar Sci* 2019, *6*, doi:10.3389/fmars.2019.00281.

25. Barrento, S.; Marques, A.; Pedro, S.; Vaz-Pires, P.; Nunes, M.L. The Trade of Live Crustaceans in Portugal: Space for Technological Improvements. *ICES Journal of Marine Science* 2008, *65*, doi:10.1093/icesjms/fsn037.

26. Barrento, S.; Marques, A.; Vaz-Pires, P.; Nunes, M.L. Live Shipment of Immersed Crabs Cancer Pagurus from England to Portugal and Recovery in Stocking Tanks: Stress Parameter Characterization. *ICES Journal of Marine Science* 2010, *67*, doi:10.1093/icesjms/fsp268.

27. Conte, F.; Voslarova, E.; Vecerek, V.; Elwood, R.W.; Coluccio, P.; Pugliese, M.; Passantino, A. Humane Slaughter of Edible Decapod Crustaceans. *Animals* 2021, *11*.

28. Fotedar, S.; Evans, L. Health Management during Handling and Live Transport of Crustaceans: A Review. *J Invertebr Pathol* 2011, *106*.

29. Barrento, S.; Marques, A.; Vaz-Pires, P.; Nunes, M.L. Physiological Changes during Simulated Live Transport of Cancer Pagurus and Recovery in Holding Tanks. *Aquac Res* 2012, *43*, doi:10.1111/j.1365-2109.2011.02943.x.

30. Farm Animal Welfare Committee *Opinion on the Welfare of Animals during Transport.*; London, 2019;

31. Paterson, B.D.; Spanoghe, P.T. Stress Indicators in Marine Decapod Crustaceans, with Particular Reference to the Grading of Western Rock Lobsters (Panulirus Cygnus) during Commercial Handling. In Proceedings of the Marine and Freshwater Research; 1997; Vol. 48.

32. Uglow, R. F., Hosie, D. A., Johnson, I. T., and Macmullen, P. H., 1986. Live handling and transport of crustacean shellfish: an investigation of mortalities. Seafish Technology SR280, MAFF R & D Commission, London. 24 pp.

33. Lu, Y.; Wang, F.; Dong, S. Energy Response of Swimming Crab Portunus Trituberculatus to Thermal Variation: Implication for Crab Transport Method. *Aquaculture* 2015, *441*, doi:10.1016/j.aquaculture.2015.02.022.

34. Burton, C. Transport of Live Crustaceans. *Shellfish News, Centre for Environment, Fisheries and Aquaculture Science* 2001, *11*, 18–19.

35. Barrento, S.; Marques, A.; Vaz-Pires, P.; Leonor Nunes, M. Cancer Pagurus (Linnaeus, 1758) Physiological Responses to Simulated Live Transport: Influence of Temperature, Air Exposure and AQUI-S®. *J Therm Biol* 2011, *36*, doi:10.1016/j.jtherbio.2010.12.006.

36. Coyle, S.D.; Tidwell, J.H.; Yasharian, D.K.; Caporelli, A.; Skudlarek, N.A. The Effect of Biomass Density, Temperature, and Substrate on Transport Survival of Market-Size Freshwater Prawn, Macrobrachium Rosenbergii. *Journal of Applied Aquaculture* 2005, *17*, doi:10.1300/J028v17n04_04.

37. Skudlarek, J.G.; Coyle, S.D.; Bright, L.A.; Tidwell, J.H. Effect of Holding and Packing Conditions on Hemolymph Parameters of Freshwater Prawns, Macrobrachium Rosenbergii, during Simulated Waterless Transport. *J World Aquac Soc* 2011, *42*, doi:10.1111/j.1749-7345.2011.00508.x.

38. Legislation.gov.uk Veterinary Surgeons Act 1966 Available online: https://www.legislation.gov.uk/ukpga/1966/36 (accessed on 13 March 2023).

39. Roth, B.; Øines, S. Stunning and Killing of Edible Crabs (Cancer). *Animal Welfare* 2010, *19*.

40. Roth, B.; Grimsbø, E. *Electrical Stunning of Edible Crabs (Cancer Pagurus): From Single Experiments to Commercial Practice*; 2016; Vol. 25;.

41. Fregin, T.; Bickmeyer, U. Electrophysiological Investigation of Different Methods of Anesthesia in Lobster and Crayfish. *PLoS One* 2016, *11*, doi:10.1371/journal.pone.0162894.

42. Weineck, K.; Ray, A.J.; Fleckenstein, L.J.; Medley, M.; Dzubuk, N.; Piana, E.; Cooper, R.L. Physiological Changes as a Measure of Crustacean Welfare under Different Standardized Stunning Techniques: Cooling and Electroshock. *Animals* 2018, *8*, doi:10.3390/ani8090158.

43. FAO Fisheries & Aquaculture. Fishing techniques - Lobster pot fishing http://www.fao.org/fishery/fishtech/1072/en (accessed June 2023).

44. FAO Fisheries & Aquaculture. Species Fact Sheets *Panulirus argus* (*Latreille*, 1804) FAO: http://www.fao.org/fishery/species/3445/en] (accessed June 2023).

45. FAO Spiny Lobster Gillnets and Trammel Nets Fishing Available online: https://www.fao.org/fishery/en/fishtech/1103/en (accessed on 21 March 2023).

46. FAO Nephrops Norvegicus (Linnaeus 1758).

47. Briggs, M. Penaeus Vannamei Available online: https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/en/en_whitelegshrimp.htm (accessed on 21 March 2023).

48. McAlain, W.; Romaire, R.; Crespi, V.; New, M. Procambarus Clarkii.

49. Ziegler, F. *Environmental Life Cycle Assessment of Norway Lobster (Nephrops Norvegicus) Fished by Creels, Conventional and Species-Selective Trawls along the Swedish West Coast.*; 2006;

50. Bernasconi, C.J.; Uglow, R.F. Effects of Emersion and Re-Immersion on Physiological and Immunological Variables in Creel-Caught and Trawled Norway Lobster Nephrops Norvegicus. *Dis Aquat Organ* 2008, *81*, doi:10.3354/dao01957.

51. Bergmann, M.; Taylor, A.C.; Geoffrey Moore, P. Physiological Stress in Decapod Crustaceans (Munida Rugosa and Liocarcinus Depurator) Discarded in the Clyde Nephrops Fishery. *J Exp Mar Biol Ecol* 2001, *259*, doi:10.1016/S0022-0981(01)00231-3.

52. Stevens, B.G. Impacts of Fishing on King Crabs: Bycatch, Injuries, and Mortality. In *King Crabs of the World: Biology and Fisheries Management*; 2014.

53. Stevens, B.G. The Ups and Downs of Traps: Environmental Impacts, Entanglement, Mitigation, and the Future of Trap Fishing for Crustaceans and Fish. *ICES Journal of Marine Science* 2021, *78*.

54. FAO Fishing Gear Types Available online: https://www.fao.org/fishery/en/geartype/search (accessed on 21 March 2023).

55. Ridgway, I.D.; Taylor, A.C.; Atkinson, R.J.A.; Stentiford, G.D.; Chang, E.S.; Chang, S.A.; Neil, D.M. Morbidity and Mortality in Norway Lobsters, Nephrops Norvegicus: Physiological, Immunological and Pathological Effects of Aerial Exposure. *J Exp Mar Biol Ecol* 2006, *328*, doi:10.1016/j.jembe.2005.07.015.

56. Albalat, A.; Sinclair, S.; Laurie, J.; Taylor, A.; Neil, D. Targeting the Live Market: Recovery of Norway Lobsters Nephrops Norvegicus (L.) from Trawl-Capture as Assessed by Stress-Related Parameters and Nucleotide Breakdown. *J Exp Mar Biol Ecol* 2010, *395*, doi:10.1016/j.jembe.2010.09.002.

57. Neil, D.M. Ensuring Crustacean Product Quality in the Post-Harvest Phase. *J Invertebr Pathol* 2012, *110*.

58. Leocádio, A.M.; Whitmarsh, D.; Castro, M. Comparing Trawl and Creel Fishing for Norway Lobster (Nephrops Norvegicus): Biological and Economic Considerations. *PLoS One* 2012, *7*, doi:10.1371/journal.pone.0039567.

59. Ridgway, I.D.; Taylor, A.C.; Atkinson, R.J.A.; Chang, E.S.; Neil, D.M. Impact of Capture Method and Trawl Duration on the Health Status of the Norway Lobster, Nephrops Norvegicus. *J Exp Mar Biol Ecol* 2006, *339*, doi:10.1016/j.jembe.2006.07.008.

60. Campos, A.; Fonseca, P.; Pilar-Fonseca, T.; Leocádio, A.M.; Castro, M. Survival of Trawl-Caught Norway Lobster (Nephrops Norvegicus L.) after Capture and Release-Potential Effect of Codend Mesh Type on Survival. *Fish Res* 2015, *172*, doi:10.1016/j.fishres.2015.07.038.

61. Gornik, S.G.; Albalat, A.; Atkinson, R.J.A.; Coombs, G.H.; Neil, D.M. The Influence of Defined Ante-Mortem Stressors on the Early Post-Mortem Biochemical Processes in the Abdominal Muscle of the Norway Lobster, Nephrops Norvegicus (Linnaeus, 1758). *Marine Biology Research* 2010, *6*, doi:10.1080/17451000903147468.

62. Romero, M.C.; Ansaldo, M.; Lovrich, G.A. Effect of Aerial Exposure on the Antioxidant Status in the Subantarctic Stone Crab Paralomis Granulosa (Decapoda: Anomura). *Comparative Biochemistry and Physiology – C Toxicology and Pharmacology* 2007, *146*, doi:10.1016/j.cbpc.2006.06.009.

63. Warrenchuk, J.J.; Shirley, T.C. Effects of Windchill on the Snow Crab (Chionoecetes Opilio). Crabs in Cold Water Regions: Biology, Management, and Economics. In *University of Alaska Sea Grant*; Paul, A.J., Dawe, E.J., Elner, R., Jamieson, G.S., Kruse, G.H., Otto, R.S., Sainte-Marie, B., Shirley, T.C., Woodby, D., Eds.; Fairbanks, 2002; pp. 81–96.

64. Butcher, P.A.; Leland, J.C.; Broadhurst, M.K.; Paterson, B.D.; Mayer, D.G. Giant Mud Crab (Scylla Serrata): Relative Efficiencies of Common Baited Traps and Impacts on Discards. *ICES Journal of Marine Science* 2012, *69*, doi:10.1093/icesjms/fss109.

65. Broadhurst, M.K.; Butcher, P.A.; Cullis, B.R. Effects of Mesh Size and Escape Gaps on Discarding in an Australian Giant Mud Crab (Scylla Serrata) Trap Fishery. *PLoS One* 2014, *9*, doi:10.1371/journal.pone.0106414.

66. Arthur, C.; Sutton-Grier, A.E.; Murphy, P.; Bamford, H. Out of Sight but Not out of Mind: Harmful Effects of Derelict Traps in Selected U.S. Coastal Waters. *Mar Pollut Bull* 2014, *86*, doi:10.1016/j.marpolbul.2014.06.050.

67. Bullimore, B.A.; Newman, P.B.; Kaiser, M.J.; Gilbert, S.E.; Lock, K.M. A Study of Catches in a Fleet of "Ghost-Fishing" Pots. *Fishery Bulletin* 2001, *99*.

68. Stevens, B.G.; Vining, I.; Byersdorfer, S.; Donaldson, W. Ghost Fishing by Tanner Crab (Chionoecetes Bairdi) Pots off Kodiak, Alaska: Pot Density and Catch per Trap as Determined from Sidescan Sonar and Pot Recovery Data. *Fishery Bulletin* 2000, *98*.

69. Butler, C.B.; Matthews, T.R. Effects of Ghost Fishing Lobster Traps in the Florida Keys. In Proceedings of the ICES Journal of Marine Science; 2015; Vol. 72.

70. Mynott, S. *Scitable: Saltwater Science*. August 24 2016,.

71. Scheld, A.M.; Bilkovic, D.M.; Havens, K.J. The Dilemma of Derelict Gear. *Sci Rep* 2016, *6*, doi:10.1038/srep19671.

72. Alverson, D.; Freeberg, M.; Murawski, S.; Pope, J. *A Global Assessment of Fisheries Bycatch and Discards.*; Rome, 1994;

73. Wassenberg, T.J.; Hill, B.J. The Effect of Trawling and Subsequent Handling on the Survival Rates of the By-Catch of Prawn Trawlers in Moreton Bay, Australia. *Fish Res* 1989, *7*, doi:10.1016/0165-7836(89)90010-6.

74. Clucas, I. A Study of the Options for Utilization of Bycatch and Discards from Marine Capture Fisheries. *FAO Circular* 1997.

75. Macbeth, W.G.; Broadhurst, M.K.; Paterson, B.D.; Wooden, M.E.L. Reducing the Short-Term Mortality of Juvenile School Prawns (Metapenaeus Macleayi) Discarded during Trawling. *ICES Journal of Marine Science* 2006, *63*, doi:10.1016/j.icesjms.2006.03.008.

76. Castro, M.; Araújo, A.; Monteiro, P.; Madeira, A.M.; Silvert, W. The Efficacy of Releasing Caught Nephrops as a Management Measure. In Proceedings of the Fisheries Research; 2003; Vol. 65.

77. Leland, J.C.; Butcher, P.A.; Broadhurst, M.K.; Paterson, B.D.; Mayer, D.G. Damage and Physiological Stress to Juvenile Eastern Rock Lobster (Sagmariasus Verreauxi) Discarded after Trapping and Hand Collection. *Fish Res* 2013, *137*, doi:10.1016/j.fishres.2012.09.001.

78. Emery, T.J.; Hartmann, K.; Green, B.S.; Gardner, C. Handled with Care: Minimal Impacts of Appendage Damage on the Growth and Productivity of the Southern Rock Lobster (Jasus Edwardsii). *Fish Res* 2016, *175*, doi:10.1016/j.fishres.2015.11.015.

79. Haupt, P.; Brouwer, S.L.; Branch, G.M.; Gäde, G. Effects of Exposure to Air on the Escape Behaviour and Haemolymph Chemistry of the South African Cape Lobster, Jasus Lalandii. *Fish Res* 2006, *81*, doi:10.1016/j.fishres.2006.07.004.

80. Soldal, A.V.; Engås, A. Survival of Young Gadoids Excluded from a Shrimp Trawl by a Rigid Deflecting Grid. *ICES Journal of Marine Science* 1997, *54*, doi:10.1006/jmsc.1996.0175.

81. Suuronen, P.; Erickson, D.L.; Orrensalo, A. Mortality of Herring Escaping from Pelagic Trawl Codends. *Fish Res* 1996, *25*, doi:10.1016/0165-7836(95)00446-7.

82. Suuronen, P.; Perez-Comas, J.A.; Lehtonen, E.; Tschernij, V. Size-Related Mortality of Herring (Clupea Harengus L.) Escaping through a Rigid Sorting Grid and Trawl Codend Meshes. *ICES Journal of Marine Science* 1996, *53*, doi:10.1006/jmsc.1996.0088.

83. Campos, A.; Fonseca, P.; Erzini, K. Size Selectivity of Diamond and Square Mesh Cod Ends for Rose Shrimp (Parapenaeus Longirostris) and Norway Lobster (Nephrops Norvegicus) off the Portuguese South Coast. *Fish Res* 2002, *58*, doi:10.1016/S0165-7836(01)00396-4.

84. Campos, A.; Fonseca, P.; Erzini, K. Size Selectivity of Diamond and Square Mesh Cod Ends for Four By-Catch Species in the Crustacean Fishery off the Portuguese South Coast. *Fish Res* 2003, *60*, doi:10.1016/S0165-7836(02)00061-9.

85. Fonseca, P.; Campos, A.; Millar, R.B. Codend Selection in the Deep-Water Crustacean Trawl Fishery in Portuguese Southern Waters. *Fish Res* 2007, *85*, doi:10.1016/j.fishres.2006.11.036.

86. Morizur, Y.; Charuau, A.; Rivoalen, J. *Survie Des Langoustines Nephrops Norvegicus s'échappant d'un Cul de Chalut*; 1982;

87. Wileman, D.A.; Sangster, G.I.; Breen, M.; Ulmestrand, M.; Soldal, A.V.; Harris, R.R. *Roundfish and Nephrops Survival after Escape from Commercial Fishing Gear.*; 1999;

88. Morris, S.; Airriess, C.N. Integration of Physiological Responses of Crustaceans to Environmental Challenge. *South African Journal of Zoology* 1998, *33*, doi:10.1080/02541858.1998.11448458.

89. Romero, M.C.; Tapella, F.; Sotelano, M.P.; Ansaldo, M.; Lovrich, G.A. Oxidative Stress in the Subantarctic False King Crab Paralomis Granulosa during Air Exposure and Subsequent Re-Submersion. *Aquaculture* 2011, *319*, doi:10.1016/j.aquaculture.2011.06.041.

90. Paterson, B.D.; Spanoghe, P.T.; Davidson, G.W.; Hosking, W.; Nottingham, S.; Jussila, J.; Evans, L.H. Predicting Survival of Western Rock Lobsters Panulirus Cygnus Using Discriminant Analysis of Haemolymph Parameters Taken Immediately Following Simulated Handling Treatments. *N Z J Mar Freshwater Res* 2005, *39*, doi:10.1080/00288330.2005.9517380.

91. van Tamelen, P.G. Estimating Handling Mortality Due to Air Exposure: Development and Application of Thermal Models for the Bering Sea Snow Crab Fishery. *Trans Am Fish Soc* 2005, *134*, doi:10.1577/t04-091.1.

92. Zainal, K.A.Y.; Taylor, A.C.; Atkinson, R.J.A. The Effect of Temperature and Hypoxia on the Respiratory Physiology of the Squat Lobsters, Munida Rugosa and Munida Sarsi (Anomura, Galatheidae). *Comp Biochem Physiol A Physiol* 1992, *101*, doi:10.1016/0300-9629(92)90509-O.

93. Taylor, H.H.; Paterson, B.D.; Wong, R.J.; Wells, R.M.G. Physiology and Live Transport of Lobsters: Report from a Workshop. In Proceedings of the Marine and Freshwater Research; 1997; Vol. 48.

94. Paterson, B.D.; Grauf, S.G.; Smith, R.A. Haemolymph Chemistry of Tropical Rock Lobsters (Panulirus Ornatus) Brought onto a Mother Ship from a Catching Dinghy in Torres Strait. In Proceedings of the Marine and Freshwater Research; 1997; Vol. 48.

95. Blue Lobster Available online: https://scottish-seafood.com/sg/blue-lobster/ (accessed on 29 March 2023).

96. Jacklin, M.; Combes, J. *The Good Practice Guide to Handling and Storing Live Crustacea*; 2007;

97. Paterson, B.D.; Goodricke, B.; Exley, P.; Smith, R. Storing Spanner Crabs (Ranini Ranini) in Air at Low Temperatures on Boats Reduces Physiological Stress and Improves Survival in Storage Tanks on Shore. *Live transport of crustaceans in air – Prolonging the survival of crabs. Report to FRDC (Project 92/71).* 1994, 7–21.

98. Patterson, L.; Dick, J.T.A.; Elwood, R.W. Physiological Stress Responses in the Edible Crab, Cancer Pagurus, to the Fishery Practice of de-Clawing. *Mar Biol* 2007, *152*, doi:10.1007/s00227-007-0681-5.

99. Manush, S.M.; Pal, A.K.; Das, T.; Mukherjee, S.C. Dietary High Protein and Vitamin C Mitigate Stress Due to Chelate Claw Ablation in Macrobrachium Rosenbergii Males. *Comparative Biochemistry and Physiology – A Molecular and Integrative Physiology* 2005, *142*, doi:10.1016/j.cbpb.2005.07.004.

100. Patterson, L.; Dick, J.T.A.; Elwood, R.W. Claw Removal and Feeding Ability in the Edible Crab, Cancer Pagurus: Implications for Fishery Practice. *Appl Anim Behav Sci* 2009, *116*, doi:10.1016/j.applanim.2008.08.007.

101. Duermit, E.; Kingsley-Smith, P.R.; Wilber, D.H. The Consequences of Claw Removal on Stone Crabs Menippe Spp. and the Ecological and Fishery Implications. *N Am J Fish Manag* 2015, *35*, doi:10.1080/02755947.2015.1064836.

102. Davis, G.E.; Baughman, D.S.; Chapman, J.D.; MacArthur, D.; Pierce, A.C. Mortality Associated with Declawing Stone Crabs, Menippe Mercenaria. *South Florida Research Center Report,* 1978, *T-552*.

103. McCambridge, C.; Dick, J.T.A.; Elwood, R.W. Effects of Autotomy Compared to Manual Declawing on Contests between Males for Females in the Edible Crab Cancer Pagurus: Implications for Fishery Practice and Animal Welfare. *J Shellfish Res* 2016, *35*, doi:10.2983/035.035.0426.

104. Bae, S.H.; Okutsu, T.; Kang, B.J.; Wilder, M.N. Alterations of Pattern in Immune Response and Vitellogenesis during Induced Ovarian Development by Unilateral and Bilateral Ablation in Litopenaeus Vannamei. *Fisheries Science* 2013, *79*, doi:10.1007/s12562-013-0652-3.

105. Aguiñaga-Cruz, J.A.; Sainz-Hernández, J.C.; Fierro-Coronado, J.A.; Diarte-Plata, G. The Effects of Eyestalk Ablation on the Reproductive and Immune Function of Female Macrobrachium Americanum. *J Aquac Res Dev* 2012, *3*.

106. Sainz-Hernández, J.C.; Racotta, I.S.; Dumas, S.; Hernández-López, J. Effect of Unilateral and Bilateral Eyestalk Ablation in Litopenaeus Vannamei Male and Female on Several Metabolic and Immunologic Variables. *Aquaculture* 2008, *283*, doi:10.1016/j.aquaculture.2008.07.002.

107. Luciane, M.; Perazzolo, L.M.; Gargioni, R.; Ogliari, P.; Margherita A.A; Barracco, M.A.A. Evaluation of Some Hemato-Immunological Parameters in the Shrimp Farfantepenaeus Paulensis Submitted to Environmental and Physiological Stress. *Aquaculture* 2002, *214*, 19–33.

108. Taylor, J.; Vinatea, L.; Ozorio, R.; Schuweitzer, R.; Andreatta, E.R. Minimizing the Effects of Stress during Eyestalk Ablation of Litopenaeus Vannamei Females with Topical Anesthetic and a Coagulating Agent. *Aquaculture* 2004, *233*, doi:10.1016/j.aquaculture.2003.09.034.

109. Diarte-Plata, G.; Sainz-Hernández, J.C.; Aguiñaga-Cruz, J.A.; Fierro-Coronado, J.A.; Polanco-Torres, A.; Puente-Palazuelos, C. Eyestalk Ablation Procedures to Minimize Pain in the Freshwater Prawn Macrobrachium Americanum. *Appl Anim Behav Sci* 2012, *140*, doi:10.1016/j.applanim.2012.06.002.

110. Zacarias, S.; Carboni, S.; Davie, A.; Little, D.C. Reproductive Performance and Offspring Quality of Non-Ablated Pacific White Shrimp (Litopenaeus Vannamei) under Intensive Commercial Scale Conditions. *Aquaculture* 2019, *503*, doi:10.1016/j.aquaculture.2019.01.018.

111. Zacarias, S.; Fegan, D.; Wangsoontorn, S.; Yamuen, N.; Limakom, T.; Carboni, S.; Davie, A.; Metselaar, M.; Little, D.C.; Shinn, A.P. Increased Robustness of Postlarvae and Juveniles from Non-Ablated Pacific Whiteleg Shrimp, Penaeus Vannamei, Broodstock Post-Challenged with Pathogenic Isolates of Vibrio Parahaemolyticus (VpAHPND) and White Spot Disease (WSD). *Aquaculture* 2021, *532*, doi:10.1016/j.aquaculture.2020.736033.

112. de Menezes, T.B.B.; Gomes, I.G.R.F.; Lucena, H.M.R.; do Nascimento Filho, K.P.; de Araújo, A.L.A.C.; de Mesquita Facundo, G.; Costa, F.H.F. Reproductive Performance of Non-Ablated Penaeus Vannamei Females in a Brazilian Commercial Hatchery/Desempenho Reprodutivo de Fêmeas Não Abladas de Penaeus Vannamei Em Uma Larvicultura Comercial Brasileira. *Brazilian Journal of Development* 2019, *5*.

113. Browdy, C.L.; Samocha, T.M. The Effect of Eyestalk Ablation on Spawning, Molting and Mating of Penaeus Semisulcatus de Haan. *Aquaculture* 1985, *49*, doi:10.1016/0044-8486(85)90187-5.

114. Benzie, J.A.H. Penaeid Genetics and Biotechnology. In Proceedings of the Aquaculture; 1998; Vol. 164.

115. Liu, S.; Gong, S.; Li, J.; Huang, W. Effects of Water Temperature, Photoperiod, Eyestalk Ablation, and Non-Hormonal Treatments on Spawning of Ovary-Mature Red Swamp Crayfish. *N Am J Aquac* 2013, *75*, doi:10.1080/15222055.2012.746247.

116. Kumlu, M.; Türkmen, S.; Kumlu, M.; Tufan Eroldo�an, O. Off-Season Maturation and Spawning of the Pacific White Shrimp Litopenaeus Vannamei in Sub-Tropical Conditions. *Turk J Fish Aquat Sci* 2011, *11*, doi:10.4194/trjfas.2011.0103.

117. Kannan D; Thirunavukkarasu P; Ashwini; Shettu N Studies on Maturation, Spawning and Hatching Wild of Shrimp Penaeus Monodon Fabrics, 1798 Collected from East Coast of India. *Journal of Aquaculture & Marine Biology* 2015, *2*, doi:10.15406/jamb.2015.02.00040.

118. Ren, S.; Mather, P.B.; Tang, B.; Hurwood, D.A. Comparison of Reproductive Performance of Domesticated Litopenaeus Vannamei Females Reared in Recirculating Tanks and Earthen Ponds: An Evaluation of Reproductive Quality of Spawns in Relation to Female Body Size and Spawning Order. *Front Mar Sci* 2020, *7*, doi:10.3389/fmars.2020.00560.

119. Coppola, C.; Tirloni, E.; Vasconi, M.; Anastasio, A.; Stella, S.; Bernardi, C. The Effects of Claw Ligatures in American Lobster (Homarus Americanus) Storage: A Preliminary Study of Haemolymph Parameters. *Acta Veterinaria Brno* 2019, *88*, doi:10.2754/avb201988030329.

120. Welsh, J.E.; King, P.A.; MacCarthy, E. Pathological and Physiological Effects of Nicking on Brown Crab (Cancer Pagurus) in the Irish Crustacean Fishery. *J Invertebr Pathol* 2013, *112*, doi:10.1016/j.jip.2012.08.006.

121. Johnson, L.; Coates, C.J.; Albalat, A.; Todd, K.; Neil, D. Temperature-Dependent Morbidity of “nicked” Edible Crab, Cancer Pagurus. *Fish Res* 2016, *175*, doi:10.1016/j.fishres.2015.11.024.

122. Chartois, H., Latrouite, D., and Le Carre, P. 1994. Stocking and transportation of live crustaceans. Report of the Directorate of Live Resources. IFREMER, Brest, France. 65 pp.

123. Beard, T.W.; McGregor, D. Storage and Care of Live Lobsters. *Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research* 1991.

124. Carder, G. A Preliminary Investigation into the Welfare of Lobsters in the UK. *Animal Sentience* 2017, *2*, doi:10.51291/2377-7478.1262.

125. Whiteley, N.M.; Taylor, E.W. Oxygen and Acid-Base Disturbances in the Hemolymph of the Lobster Homarus Gammarus During Commercial Transport and Storage. *Journal of Crustacean Biology* 1992, *12*, doi:10.2307/1548715.

126. Salin, K.R. Live Transportation of Macrobrachium Rosenbergii (De Man) in Chilled Sawdust. In Proceedings of the Aquaculture Research; 2005; Vol. 36.

127. Lorentzen, G.; Lian, F.; Siikavuopio, S.I. Live Holding of Snow Crab (Chionoecetes Opilio) at 1 and 5 °C without Feeding — Quality of Processed Clusters. *Food Control* 2020, *114*, doi:10.1016/j.foodcont.2020.107221.

128. Siikavuopio, S.I.; James, P.; Olsen, B.R.; Evensen, T.; Mortensen, A.; Olsen, S.H. Holding Wild Snow Crab, Chionoecetes Opilio: Effects of Stocking Density and Feeding on Survival and Injury. *Aquac Res* 2017, *48*, doi:10.1111/are.12993.

129. Esposito, G.; Nucera, D.; Meloni, D. Retail Stores Policies for Marketing of Lobsters in Sardinia (Italy) as Influenced by Different Practices Related to Animal Welfare and Product Quality. *Foods* 2018, *7*, doi:10.3390/foods7070103.

130. Bennison, S. *Guidelines on Aquatic Animal Welfare for the Aquaculture Industry in Western Australia.*; 2000;

131. Karavanich, C.; Atema, J. Individual Recognition and Memory in Lobster Dominance. *Anim Behav* 1998, *56*, doi:10.1006/anbe.1998.0914.

132. Hall, M.R.; van Ham, E.H. The Effects of Different Types of Stress on Blood Glucose in the Giant Tiger Prawn Penaeus Monodon. *J World Aquac Soc* 1998, *29*, doi:10.1111/j.1749-7345.1998.tb00649.x.

133. Siikavuopio, S.I.; James, P. Effects of Temperature on Feed Intake, Growth and Oxygen Consumption in Adult Male King Crab Paralithodes Camtschaticus Held in Captivity and Fed Manufactured Diets. *Aquac Res* 2015, *46*, doi:10.1111/are.12207.

134. Siikavuopio, S.I.; James, P.; Olsen, B.R.; Evensen, T.; Mortensen, A. Holding Wild Caught Red King Crab, Paralithodes Camtschaticus: Effects of Stocking Density and Feeding on Survival and Meat Content. *Aquac Res* 2016, *47*, doi:10.1111/are.12546.

135. Vijayakumaran, M.; Radhakrishnan, E. v. Live Transport and Marketing of Spiny Lobsters in India. In Proceedings of the Marine and Freshwater Research; 1997; Vol. 48.

136. Wickins, J.F.; Lee, D.O. *Crustacean Farming: Ranching and Culture*; Wickins, J.F., Lee, D.O., Eds.; 2nd ed.; Blackwell: Oxford, 2002; ISBN 9780632054640.

137. Lorenzo, R.A.; Tapella, F.; Romero, M.C. Transportation Methods for Southern King Crab: From Fishing to Transient Storage and Long-Haul Packaging. *Fish Res* 2020, *223*, doi:10.1016/j.fishres.2019.105441.

138. Legislation.gov.uk Council Regulation (EC) No 1/2005 of 22 December 2004 on the Protection of Animals during Transport and Related Operations and Amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97.

139. Lu, Y.; Zhu, B.; Zhang, D.; Li, Y. Air Temperature and Emersion Time Can Affect the Survival Rate and Ammonium Loading of Swimming Crab Portunus Trituberculatus Exposed to Air. *Journal of Ocean University of China* 2020, *19*, doi:10.1007/s11802-020-4154-5.

140. Lorentzen, G.; Lian, F.; Siikavuopio, S.I. Quality Parameters of Processed Clusters of Red King Crab (Paralithodes Camtschaticus) – Effects of Live Holding at 5 and 10 °C up to 92 Days without Feeding. *Food Control* 2019, *95*, doi:10.1016/j.foodcont.2018.07.041.

141. Sacristán, H.J.; Rodríguez, Y.E.; de los Angeles Pereira, N.; López Greco, L.S.; Lovrich, G.A.; Fernández Gimenez, A.V. Energy Reserves Mobilization: Strategies of Three Decapod Species. *PLoS One* 2017, *12*, e0184060, doi:10.1371/journal.pone.0184060.

142. Elwood, R.W.; Ingle, R.W. *The UFAW Handbook on the Care and Management of Laboratory and Other Research Animals*; Golledge, H., Richardson, C., Eds.; 9th ed.; Wiley Blackwell, 2020;

143. Scholnick, D.A.; Haynes, V.N. Influence of Hypoxia on Bacteremia in the Dungeness Crab, Cancer Magister. *Biological Bulletin* 2012, *222*, doi:10.1086/BBLv222n1p56.

144. Lorenzon, S.; Giulianini, P.G.; Martinis, M.; Ferrero, E.A. Stress Effect of Different Temperatures and Air Exposure during Transport on Physiological Profiles in the American Lobster Homarus Americanus. *Comparative Biochemistry and Physiology – A Molecular and Integrative Physiology* 2007, *147*, doi:10.1016/j.cbpa.2006.11.028.

145. Edwards, E. *The Edible Crab: And Its Fishery in British Waters.*; Buckland Foundation Books: Farnham, 1979;

146. APEC Fisheries Working Group *Air Shipment of Live and Fresh Fish and Seafood Guidelines.*; Singapore, 1999;

147. Morrissy, N., Walker, P., Fellows, C. and Moore, W., 1999. An Investigation of Weight Loss of Marron (*Cherax tenuimanus*) During Live Transport to Market. Fisheries Research Report 009. Department of Fisheries WA.

148. Department of Fisheries Western Australia; W.A. Marron Growers Association; SQMI Project; Pemberton Aquaculture Producers *Code of Practice for the Harvest and Post Harvest Handling of Live Marron for Food.*; Perth, 2002;

149. Spanoghe, P.T.; Bourne, P.K. Relative Influence of Environmental Factors and Processing Techniques on Panulirus Cygnus Morbidity and Mortality during Simulated Live Shipments. In Proceedings of the Marine and Freshwater Research; 1997; Vol. 48.

150. Powell, A.; Cowing, M.; Eriksson, S.; Johnson, M. Physiological Stress Associated with Physical Trauma during Transportation of the Norway Lobster, Nephrops Norvegicus. *PeerJ Prepr* 2015.

151. Powell, A.; Cowing, D.M.; Eriksson, S.P.; Johnson, M.L. Stress Response According to Transport Protocol in Norway Lobster, *Nephrops Norvegicus*. *Crustacean Research* 2017, *46*, doi:10.18353/crustacea.46.0_17.

152. Tidau, S. and Briffa, M., 2016. Review on behavioral impacts of aquatic noise on crustaceans. *Proceedings of the Fourth International Conference on the Effects of Noise on Aquatic Life* Dublin, Ireland 10-16 July 2016.

153. Filiciotto, F.; Vazzana, M.; Celi, M.; Maccarrone, V.; Ceraulo, M.; Buffa, G.; Stefano, V. di; Mazzola, S.; Buscaino, G. Behavioural and Biochemical Stress Responses of Palinurus Elephas after Exposure to Boat Noise Pollution in Tank. *Mar Pollut Bull* 2014, *84*, doi:10.1016/j.marpolbul.2014.05.029.

154. Celi, M.; Filiciotto, F.; Vazzana, M.; Arizza, V.; Maccarrone, V.; Ceraulo, M.; Mazzola, S.; Buscaino, G. Shipping Noise Affecting Immune Responses of European Spiny Lobster (Palinurus Elephas). *Can J Zool* 2015, *93*, doi:10.1139/cjz-2014-0219.

155. Fotedar, S.; Tsvetnenko, E.; Evans, L. Effect of Air Exposure on the Immune System of the Rock Lobster Panulirus Cygnus. In Proceedings of the Marine and Freshwater Research; 2001; Vol. 52.

156. Allen, G.J.P.; Wang, M.C.; Tseng, Y.C.; Weihrauch, D. Effects of Emersion on Acid–Base Regulation, Osmoregulation, and Nitrogen Physiology in the Semi-Terrestrial Mangrove Crab, Helice Formosensis. *J Comp Physiol B* 2021, *191*, doi:10.1007/s00360-021-01354-0.

157. Durand, F.; Chausson, F.; Regnault, M. Increases in Tissue Free Amino Acid Levels in Response to Prolonged Emersion in Marine Crabs: An Ammonia-Detoxifying Process Efficient in the Intertidal Carcinus Maenas but Not in the Subtidal Necora Puber. *Journal of Experimental Biology* 1999, *202*, doi:10.1242/jeb.202.16.2191.

158. Durand, F.; Regnault, M. Nitrogen Metabolism of Two Portunid Crabs, Carcinus Maenas and Necora Puber, during Prolonged Air Exposure and Subsequent Recovery: A Comparative Study. *Journal of Experimental Biology* 1998, *201*, doi:10.1242/jeb.201.17.2515.

159. Durand, F.; Devillers, N.; Lallier, F.H.; Regnault, M. Nitrogen Excretion and Changes in Blood Components during Emersion of the Subtidal Spider Crab Maia Squinado (L.). *Comparative Biochemistry and Physiology – A Molecular and Integrative Physiology* 2000, *127*, doi:10.1016/S1095-6433(00)00253-1.

160. Spicer, J.I.; Hill, A.D.; Taylor, A.C.; Strang, R.H.C. Effect of Aerial Exposure on Concentrations of Selected Metabolites in Blood of the Norwegian Lobster Nephrops Norvegicus (Crustacea: Nephropidae). *Mar Biol* 1990, *105*, doi:10.1007/BF01344278.

161. Duan, Y.; Zhang, Y.; Dong, H.; Zhang, J. Effect of Desiccation on Oxidative Stress and Antioxidant Response of the Black Tiger Shrimp Penaeus Monodon. *Fish Shellfish Immunol* 2016, *58*, doi:10.1016/j.fsi.2016.09.004.

162. Liu, H.L.; Yang, S.P.; Wang, C.G.; Chan, S.M.; Wang, W.X.; Feng, Z.H.; Sun, C.B. Effect of Air Exposure and Resubmersion on the Behavior and Oxidative Stress of Pacific White Shrimp Litopenaeus Vannamei. *N Am J Aquac* 2015, *77*, doi:10.1080/15222055.2014.955157.

163. Dong, Z.; Mao, S.; Chen, Y.; Ge, H.; Li, X.; Wu, X.; Liu, D.; Zhang, K.; Bai, C.; Zhang, Q. Effects of Air-Exposure Stress on the Survival Rate and Physiology of the Swimming Crab Portunus Trituberculatus. *Aquaculture* 2019, *500*, doi:10.1016/j.aquaculture.2018.10.049.

164. Webster, S.G. Measurement of Crustacean Hyperglycaemic Hormone Levels in the Edible Crab Cancer Pagurus during Emersion Stress. *Journal of Experimental Biology* 1996, *199*, doi:10.1242/jeb.199.7.1579.

165. Schmitt, A.S.C.; Uglow, R.F. Haemolymph Constituent Levels and Ammonia Efflux Rates of Nephrops Norvegicus during Emersion. *Mar Biol* 1997, *127*, doi:10.1007/s002270050027.

166. Bernardi, C.; Baggiani, L.; Tirloni, E.; Stella, S.; Colombo, F.; Moretti, V.M.; Cattaneo, P. Hemolymph Parameters as Physiological Biomarkers in American Lobster (Homarus Americanus) for Monitoring the Effects of Two Commercial Maintenance Methods. *Fish Res* 2015, *161*, doi:10.1016/j.fishres.2014.08.013.

167. Simon, C.J.; Mendo, T.C.; Green, B.S.; Gardner, C. Predicting Transport Survival of Brindle and Red Rock Lobsters Jasus Edwardsii Using Haemolymph Biochemistry and Behaviour Traits. *Comp Biochem Physiol A Mol Integr Physiol* 2016, *201*, doi:10.1016/j.cbpa.2016.07.001.

168. I, A.; R, F. Survival and Immunity of Marron Cherax Cainii (Austin, 2002) Fed Bacillus Mycoides Supplemented Diet under Simulated Transport. *J Aquac Res Dev* 2015, *07*, doi:10.4172/2155-9546.1000390.

169. Cheng, W.; Liu, C.H.; Kuo, C.M. Effects of Dissolved Oxygen on Hemolymph Parameters of Freshwater Giant Prawn, Macrobrachium Rosenbergii (de Man). *Aquaculture* 2003, *220*, doi:10.1016/S0044-8486(02)00534-3.

170. le Moullac, G.; Haffner, P. Environmental Factors Affecting Immune Responses in Crustacea. *Aquaculture* 2000, *191*, doi:10.1016/S0044-8486(00)00422-1.

171. le Moullac, G.; Soyez, C.; Saulnier, D.; Ansquer, D.; Avarre, J.C.; Levy, P. Effect of Hypoxic Stress on the Immune Response and the Resistance to Vibriosis of the Shrimp Penaeus Stylirostris. *Fish Shellfish Immunol* 1998, *8*, doi:10.1006/fsim.1998.0166.

172. Crear, B.J.; Forteath, G.N.R. Flow-Rate Requirements for Captive Western Rock Lobsters (Panulirus Cygnus): Effects of Body Weight, Temperature, Activity, Emersion, Daily Rhythm, Feeding and Oxygen Tension on Oxygen Consumption. *Mar Freshw Res* 2001, *52*, doi:10.1071/MF00004.

173. Mehrtens, F.; Stolpmann, M.; Buchholz, F.; Hagen, W.; Saborowski, R. Locomotory Activity and Exploration Behaviour of Juvenile European Lobsters (Homarus Gammarus) in the Laboratory. *Mar Freshw Behav Physiol* 2005, *38*, doi:10.1080/10236240500104101.

174. Meyer-Rochow, V.B. Light-Induced Damage to Photoreceptors of Spiny Lobsters and Other Crustaceans. *Crustaceana* 2014, *64*.

175. Meyer-Rochow, V.B. The Crustacean Eye: Dark/ Light Adaptation, Polarization Sensitivity, Flicker Fusion Frequency, and Photoreceptor Damage. *Zoolog Sci* 2001, *18*, 1175–1197.

176. Elwood, R.W. Discrimination between Nociceptive Reflexes and More Complex Responses Consistent with Pain in Crustaceans. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2019, *374*.

177. Magee, B.; Elwood, R.W. Trade-Offs between Predator Avoidance and Electric Shock Avoidance in Hermit Crabs Demonstrate a Non-Reflexive Response to Noxious Stimuli Consistent with Prediction of Pain. *Behavioural Processes* 2016, *130*, doi:10.1016/j.beproc.2016.06.017.

178. Aspaas, S.; Grefsrud, E.S.; Fernö, A.; Jensen, K.H.; Trengereid, H.; Agnalt, A.L. An Enriched Environment Promotes Shelter-Seeking Behaviour and Survival of Hatchery-Produced Juvenile European Lobster (Homarus Gammarus). *PLoS One* 2016, *11*, doi:10.1371/journal.pone.0159807.

179. Carere, C.; della Gala, M.; Saraga, E.; Grignani, G.; Delle Fratte, R.; Carlini, A.; Angeletti, D.; Alleva, E.; Mather, J.A.; Nascetti, G. *The Shelter Matters: Effect of Rearing Conditions on the Behavioural Proles of Juvenile Lobsters (Homarus Gammarus) Bred for Restocking Purposes.*; Viterbo, 2012;

180. Candotti, P. *Sofferenza Di Aragoste e Astici Vivi Con Chele Legate e Su Letto Di Ghiaccio Durante La Fase Di Commercializzazione.*; 2007;

181. Morris, S.; Oliver, S. Circulatory, Respiratory and Metabolic Response to Emersion and Low Temperature of Jasus Edwardsii: Simulation Studies of Commercial Shipping Methods. *Comparative Biochemistry and Physiology – A Molecular and Integrative Physiology* 1999, *122*, doi:10.1016/S1095-6433(99)00003-3.

182. Gomez-Jimenez, S.; Uglow, R.F.; Gollas-Galvan, T. The Effects of Cooling and Emersion on Total Haemocyte Count and Phenoloxidase Activity of the Spiny Lobster Panulirus Interruptus. *Fish Shellfish Immunol* 2000, *10*, doi:10.1006/fsim.2000.0277.

183. Lu, Y.; Zhang, D.; Wang, F.; Dong, S. Hypothermal Effects on Survival, Energy Homeostasis and Expression of Energy-Related Genes of Swimming Crabs Portunus Trituberculatus during Air Exposure. *J Therm Biol* 2016, *60*, doi:10.1016/j.jtherbio.2016.06.007.

184. McGaw, I.J.; Whiteley, N.M. Effects of Acclimation and Acute Temperature Change on Specific Dynamic Action and Gastric Processing in the Green Shore Crab, Carcinus Maenas. *J Therm Biol* 2012, *37*, doi:10.1016/j.jtherbio.2012.07.003.

185. Samet, M.; Nakamura, K.; Nagayama, T. Tolerance and Respiration of the Prawn (Penaeus Japonicus) under Cold Air Conditions. *Aquaculture* 1996, *143*, doi:10.1016/0044-8486(96)01263-X.

186. IFFO Codex Alimentarius International Food Standards.

187. Císař, P.; Saberioon, M.; Kozák, P.; Pautsina, A. Fully Contactless System for Crayfish Heartbeat Monitoring: Undisturbed Crayfish as Bio-Indicator. *Sens Actuators B Chem* 2018, *255*, doi:10.1016/j.snb.2017.07.160.

188. Hundley, P.L.J.; Francis, M.; Drennan, D.; Benzel, G. Fundamental Design and Management of Live Aquatic Holding Systems with an Emphasis on Moderating the Effects of Shock Loading. In *Marketing and Shipping Live Aquatic Products*; 1997; pp. 186–196.

189. Lorenzon, S.; Giulianini, P.G.; Libralato, S.; Martinis, M.; Ferrero, E.A. Stress Effect of Two Different Transport Systems on the Physiological Profiles of the Crab Cancer Pagurus. *Aquaculture* 2008, *278*, doi:10.1016/j.aquaculture.2008.03.011.

190. Cheng, W.; Chen, S.M.; Wang, F.I.; Hsu, P.I.; Liu, C.H.; Chen, J.C. Effects of Temperature, PH, Salinity and Ammonia on the Phagocytic Activity and Clearance Efficiency of Giant Freshwater Prawn Macrobrachium Rosenbergii to Lactococcus Garvieae. *Aquaculture* 2003, *219*, doi:10.1016/S0044-8486(03)00017-6.

191. Neil, D. *The Effect of the CrustastunTM on Nerve Activity in Crabs and Lobsters.*; 2010;

192. Neil, D.; Thompson, J. *The Stress Induced by the CrustastunTM Process in Two Commercially Important Decapod Crustaceans: The Edible Brown Cancer Pagurus and the European Lobster Homarus Gammarus*; 2012;

193. Diggles, B.; Browman, H. Review of Some Scientific Issues Related to Crustacean Welfare. *ICES Journal of Marine Science* 2018, *76*, 66–81.

194. Jury, S.H.; Watson, W.H. Seasonal and Sexual Differences in the Thermal Preferences and Movements of American Lobsters. *Canadian Journal of Fisheries and Aquatic Sciences* 2013, *70*, doi:10.1139/cjfas-2013-0061.

195. Mood, A. Welfare during Killing of Crabs, Lobsters and Crayfish Available online: http://fishcount.org.uk/welfare-of-crustaceans/welfare-during-killing-of-crabs-lobsters-and-crayfish (accessed on 1 July 2021).

196. Tang, L.S.; Goeritz, M.L.; Caplan, J.S.; Taylor, A.L.; Fisek, M.; Marder, E. Precise Temperature Compensation of Phase in a Rhythmic Motor Pattern. *PLoS Biol* 2010, *8*, doi:10.1371/journal.pbio.1000469.

197. Tang, L.S.; Taylor, A.L.; Rinberg, A.; Marder, E. Robustness of a Rhythmic Circuit to Short- and Long-Term Temperature Changes. *Journal of Neuroscience* 2012, *32*, doi:10.1523/JNEUROSCI.1443-12.2012.

198. Marder, E. Variability, Compensation, and Modulation in Neurons and Circuits. *Proc Natl Acad Sci U S A* 2011, *108*, doi:10.1073/pnas.1010674108.

199. EFSA Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a Request from the Commission Related to the Aspects of the Biology and Welfare of Animals Used for Experimental and Other Scientific Purposes. *EFSA Journal* 2005, *3*, 292, doi:10.2903/j.efsa.2005.292.

200. RSPCA Australia, 2018. Humane killing of crustaceans for human consumption. https://kb.rspca.org.au/wp-content/uploads/2019/01/Humane-killing-of-crustaceans-for-human-consumption-%E2%80%93-RSPCA-Information-Paper-May-2018.pdf (Accessed June 2023).

201. Gardner, C. Options for Humanely Immobilizing and Killing Crabs. *J Shellfish Res* 1997, *16*.

202. Chung, Y.S.; Cooper, R.M.; Graff, J.; Cooper, R.L. The Acute and Chronic Effect of Low Temperature on Survival, Heart Rate and Neural Function in Crayfish (<I>Procambarus Clarkii</I>) and Prawn (<I>Macrobrachium Rosenbergii</I>) Species. *Open J Mol Integr Physiol* 2012, *02*, doi:10.4236/ojmip.2012.23011.

203. Wycoff, S.; Weineck, K.; Conlin, S.; Suryadevara, C.; Grau, E.; Bradley, A.; Cantrell, D.; Eversole, S.; Grachen, C.; Hall, K.; et al. *Effects of Clove Oil (Eugenol) on Proprioceptive Neurons , Heart Rate , and Behavior in Model Crustaceans*; 2018; Vol. 145;.

204. Bierbower, S.M.; Cooper, R.L. The Effects of Acute Carbon Dioxide on Behavior and Physiology in Procambarus Clarkii. *J Exp Zool A Ecol Genet Physiol* 2010, *313 A*, doi:10.1002/jez.620.

205. Bierbower, S.M.; Cooper, R.L. The Mechanistic Action of Carbon Dioxide on a Neural Circuit and NMJ Communication. *J Exp Zool A Ecol Genet Physiol* 2013, *319*, 340–354, doi:10.1002/jez.1798.

206. Paietta, E.N.; Hartzler, L.K. Impact of a CO2 Gradient on the Behavior of the Red Crayfish, Procambarus Clarkii. *Biological Sciences Student Publications* 2017.

207. Adams, R.; Stanley, C.E.; Piana, E.; Cooper, R.L. Physiological and Behavioral Indicators to Measure Crustacean Welfare. *Animals* 2019, *9*, doi:10.3390/ani9110914.

208. Dan H. Live Lobsters Torn Apart in Agony in Shocking Eyewitness Video Available online: https://www.peta.org.uk/blog/live-lobsters-torn-apart-in-agony-in-shocking-eyewitness-video/ (accessed on 27 February 2023).

209. Mitchell & Cooper CRUSTASTUN Available online: https://www.mitchellcooper.co.uk/appliances/crustastun-12749 (accessed on 27 February 2023).

210. Roth, B., & Grimsbø, E. 2016. Electrical stunning of edible crabs (Cancer pagurus): from single experiments to commercial practice. *Animal Welfare*, 25, 489-497.

211. Spector, D. This “Big Mother Shucker” Can Kill A Lobster In 6 Seconds Available online: https://www.businessinsider.com/the-big-mother-shucker-can-kill-a-lobster-in-6-seconds-2013-9?r=US&IR=T (accessed on 27 September 2013).

212. HPP Seafood: Shells Away with High Pressure Processing (HPP) Shucking Available online: https://www.hiperbaric.com/en/hpp-seafood-shells-away-with-high-pressure-processing-shucking/ (accessed on 21 March 2023).

213. Golan, H.; Colton, J.S.; Moore, H.J.; Grossman, Y. Analysis of Evoked and Spontaneous Quantal Release at High Pressure in Crustacean Excitatory Synapses. *Pflugers Arch* 1995, *430*, doi:10.1007/BF00386155.

214. Golan, H.; Moore, H.J.; Grossman, Y. Pressure Exposure Unmasks Differences in Release Properties between High and Low Yield Excitatory Synapses of a Single Crustacean Axon. *Neuropharmacology* 1996, *35*, doi:10.1016/0028-3908(95)00173-5.

215. Yue, S. The Welfare of Crustaceans at Slaughter. HSUS Reports: Farm Industry Impacts on Animals 2008, Paper 4.

216. National Aquaculture Council Aquatic Animal Welfare Guidelines: Guidelines on Welfare of Fish and Crustaceans in Aquaculture and/or in Live Holding Systems for Human Consumption. 2017.

217. Baker, J.R. Experiments on the Humane Killing of Crabs. *Journal of the Marine Biological Association of the United Kingdom* 1955, *34*, doi:10.1017/S0025315400008572.

218. Thabet, R.; Ayadi, H.; Koken, M.; Leignel, V. Homeostatic Responses of Crustaceans to Salinity Changes. *Hydrobiologia* 2017, *799*.

219. Tautz, J. & Sandeman, D.C. The Detection of Waterborne Vibration by Sensory Hairs on the Chelae of the Crayfish. *J Exp Biol* 1980, 88, doi:10.1242/jeb.88.1.351

220. Barr, S., Laming, P. R., Dick, J. T. A., & Elwood, R, W. Nociception or pain in a decapod crustacean? *Animal Behaviour* 2008, 75, doi: 10.1016/j.anbehav.2007.07.004

CRUSTACEAN COMPASSION

Email: info@crustaceancompassion.org

Website: www.crustaceancompassion.org

Twitter: @crab_welfare