Vibrios as causal agents of zoonoses

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Vibrios as causal agents of zoonoses

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Abstract

Vibrios are Gram-negative rod shaped bacteria that are widespread in the coastal and estuarine environments. Some species, e.g. *Vibrio anguillarum* and *V. tapetis,* comprise serious pathogens of aquatic vertebrates or invertebrates. Other groups, including *Grimontia (= Vibrio) hollisae, Photobacterium (= Vibrio) damselae* subsp. *damselae, V. alginolyticus, V. carchariae (= V. harveyi), V. cholerae, V. fluvialis, V. furnissii, V. metschnikovii, V. mimicus, V. parahaemolyticus* and *V. vulnificus,* may cause disease in both aquatic animals and humans. The human outbreaks, although low in number, typically involve wound infections and gastro-intestinal disease often with watery diarrhoea. In a minority of cases, for example *V. vulnificus,* there is good evidence to actually associate human infections with diseased animals. In other cases, the link is certainly feasible but hard evidence is mostly lacking.

Keywords: Vibrios; Fish; Invertebrates; Wound infections; Gastro-enteritis

Contents

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1. **Introduction**

The vibrios are Gram-negative rod shaped bacteria that are fermentative, catalase and oxidase positive, motile by polar flagella, are usually sensitive to the vibriostatic agent, O/129, and mostly have a requirement for sodium chloride (Farmer et al., 2005). Taxonomic improvements have resulted in some vibrios transferred to new genera, e.g. *Vibrio hollisae* which was re-classified to the newly created genus *Grimontia* as *G. hollisae,* or moved to other genera, e.g. *V. damsela* which was transferred to *Photobacterium* as *P. damselae* (Farmer et al., 2005). The organisms are generally widespread in the coastal and estuarine environments; some species, e.g. *V. parahaemolyticus,* are commonplace in/on aquatic animals, notably invertebrates (Farmer et al., 2005). Certainly, a steadily increasing number of taxa, e.g. *V. anguillarum* and *V. tapetis,* have been associated with diseases of aquatic animals, whereas other species, e.g. *V. cholerae,* comprise serious pathogens of humans (Farmer et al., 2005; Austin and Austin, 2007). A comparatively small number of species, e.g. *V. parahaemolyticus* and *V. vulnificus,* cause disease in both aquatic animals and humans. However, there is a dilemma that because an organism occurs in an aquatic animal, it does not necessarily mean that this is the source of human infections. Indeed, the evidence linking vibrios with zoonoses is at best incomplete and sometimes the subject of conjecture. Fortunately, the number of cases of human diseases that may be traced to animals is small, although comprehensive official statistics are missing. The candidates for discussion include *G. hollisae, P. damselae* subsp. *damselae, V. alginolyticus, V. harveyi (= V. carchariae), V. cholerae, V. fluvialis, V. furnissii, V. metschnikovii, V. mimicus, V. parahaemolyticus* and *V. vulnificus* (Table 1). It should be emphasized that the source of most of the organisms causing human

disease cannot be linked definitively to animals. Indeed, the origin of some of these bacteria may well be the waters in which the aquatic animals are found. Transmission to humans is inevitably via wound or may be food/water borne and involving direct entry into the digestive tract. Certainly, all the taxa included in this review have the potential to cause human disease although the evidence for a definite link between animals and humans is not always proven. The narrative will be divided into those organisms, e.g. *V. vulnificus,* for which there is a higher risk and good evidence linking them with zoonoses, and those for which the risk is lower and the data may be more uncertain.

2. Higher risk organisms

Three taxa, namely *V. cholerae, V. parahaemolyticus* and *V. vulnificus,* have been either repeatedly involved in disease outbreaks or have the potential to do so.

2.1. *Vibrio cholerae*

An epizootic, attributed to *V. cholerae* occurred in a wild population of ayu (*Plecoglossus altivelis*) in the River Amano, Japan, with disease signs including petechial haemorrhages on the body surface and congestion of the organs (Austin and Austin, 2007). A similar organism was recovered from septicaemic goldfish in Australia and from sharks (see Austin and Austin, 2007). Also, there is some indication that *V. cholerae* (non-O1 and O139) may be involved in shrimp disease, specifically of *Penaeus monodon* (Haldari et al., 2007) and ornamental fish (Swaminathan et al., 2007) in India. Infectivity experiments suggested that *V. cholerae* was highly virulent to ayu and eels following immersion in 1.26×10^4 cells ml^{-1} and 1.26×10^2 cells ml^{-1}, respectively. Yamanoi et al. (1980) reported

that with ayu, mortalities began in 2-7 days at water temperatures of 21 and 26^{O}C, but deaths did not occur if the water temperature was at only 16^{O}C. Only 10% mortalities occurred in eels within 5 days at a water temperature of 21^{O}C, and 30% deaths in 3-7 days at 26^{O}C.

V. cholerae is the cause of the human pandemics of cholerae, which is caused by cholera-toxin producing strains, and develop into extreme gastro-enteritis with copious quantities of watery diarrhoea leading to dehydration (Morris, 2003). Historically, cholera has been associated with toxigenic serogroup O1 strains, but subsequently there was the emergence of cholera-toxin producing ability in other groups, i.e. serogroup O139/non-O1. The question of relevance to the current context is whether or not strains from aquatic animals carry the toxin gene? Unfortunately, there is indeed evidence that some of the environmental isolates have been associated with toxigenicity. Toxin-gene (*ctxA* and *zot*) carrying strains have most certainly been recovered from marine waters off the west coast of USA (Jiang et al., 2003).

The source of some outbreaks has been linked with contaminated shellfish, including raw oysters (Morris, 2003) and crabs (CDC, 1991), and involves non-O1 and non-O139 strains (Farama et al., 2008). An outbreak of cholera in Louisiana, USA in 1978 was associated with shellfish caught in the Gulf of Mexico (Blake et al., 1980). Crabs, which had been transported from Ecuador to New York in 1991, resulted in three individuals developing cholera. These people and samples of crab meat revealed the presence of the pathogen (CDC, 1991). Also, cells have been transferred in the water used to transport ornamental fish from countries in

which cholera occurs (Manfrin et al., 2001). In one study between 1997 and 1998, 34 out of 420 water samples (= 8.09% of the total) revealed the presence of *V. cholerae* non-O1, and it was considered that their enterotoxins could pose a potential risk of gastro-enteritis in humans especially those operating aquaria or keeping pet fish (Manfrin et al., 2001).

2.2. *Vibrio parahaemolyticus*

The organism has been associated with mortalities in Iberian toothcarp (*Aphanius iberus*) with the signs centering on external haemorrhages, and tail rot (Austin and Austin, 2007). Cultures regarded as intermediate between *V. alginolyticus* and *V. parahaemolyticus* were recovered from diseased milkfish (*Chanos chanos*) in the Philippines (Austin and Austin, 2007). Certainly, *V. parahaemolyticus* is a well-recognized pathogen of invertebrates, including abalone, *Haliotis diversicolor supertexta* (e.g. Cai et al., 2007) and shrimp (e.g. Jayasree et al., 2006). Disease signs in abalone include a change in colour to white and a detachment from the diatom films on which they are cultured (Cai et al., 2007). In *Penaeus monodon,* the organism has been implicated as a cause of red disease in India (Jayasree et al., 2006). Pathogenicity has been established in tiger prawns with the LD_{50} dose of 1 x 10^5 CFU $shrimp^{-1}$ (Sudheesh and Xu, 2001). The corresponding value in abalone post-larvae was 3.5 x 10^5 CFU ml^{-1} with the disease mirroring that of natural infections (Cai et al., 2007).

V. parahaemolyticus may spread into humans orally via contaminated food, particularly molluscs such as oysters (DePaola et al., 2003; Drake et al., 2007) leading to the development of acute gastro-enteritis with diarrhoea (Cho et al.,

2008). In Denmark during 1987-1992, the organism was recovered from 13 patients of whom 3 and 10 displayed wound and ear infections, respectively. With many cases, there was a prior association with the marine environment (Hornstrup and Gahrnhansen, 1993). A seasonality in diarrhoeal cases, which was not linked to age, was reported in Korea between 2004-2006 (Cho et al., 2008). Virulence factors centre on proteases, ß-haemolysins, notably the thermostable direct haemolysin (tdh) and the tdh-related haemolysin (trh), adhesins and the expression of *V. cholerae* virulence genes including the *toxR* operons (DePaola et al., 2003; Snoussi et al., 2008).,

2.3. *Vibrio vulnificus*

The organism was recognized as a serious pathogen of eels in Japan during the 1970's with subsequent cases in Spain and Denmark (Austin and Austin, 2007). In addition, *V. vulnificus* has been mentioned as a cause of disease in *Penaeus monodon* in India (Jayasree et al., 2006). Overall, the disease is characterized by haemorrhaging seen as redness on the body surface, and later as involvement of the gastro-intestinal tract, gills, heart, liver and spleen (Austin and Austin, 2007). In 2005, the pathogen caused substantial mortality in farmed ovate pompano *(Trachinotus ovatus)* in P.R.C., with signs including external haemorrhaging and ulcers, and haemorrhaging of the gills, intestine and liver (Li et al., 2006). A new serogroup, i.e. *V. vulnificus* biotype 2 serovar A was recognized in Spain in 2000 and Denmark by 2004; the affected eels demonstrated extensive haemorrhaging and necrosis (Fouz et al., 2006). *V. vulnificus* has been recovered from fish caught in the US Gulf Coast (DePaola et al., 1994), with minimum and maximum numbers occurring in winter and April to October, respectively DePaola et al.

185 (1994). The highest levels, i.e. 10^8 bacteria 100 g^{-1}, were associated with the gut
186 contents of bottom-feeding fish, which ate molluscs and crustacea. Lower
187 populations were recovered from plankton-feeding fish, i.e. 10^5 *V. vulnificus* cells
188 100 g^{-1}.
189
190 A vaccine, named Vulnivaccine, which inactivated whole cells, comprises
191 capsular antigens and toxoids of serovar E was administered by immersion for 1 h
192 in three doses at 12 day intervals, and led to good protection in eels (RPS = 60-
193 90%) (Esteve-Gassent et al., 2003). During field trials by prolonged immersion
194 and boostering after 14 and 24-28 days of 9.5 million glass eels in Spain and with
195 parallel work in Denmark, Vulnivaccine led to an RPS of 62-86% (Fouz et al.,
196 2001). With the appearance of a second serotype of *V. vulnificus*, i.e. A, a bivalent
197 vaccine was formulated, and determined to be protective following oral
198 application, by anal and oral intubation, and by intraperitoneal injection (RPS =
199 80-100%) (Esteve-Gassent et al., 2004).
200
201 In human, *V. vulnificus* has been associated with a small but increasing number
202 of serious life-threatening conditions, many stemming from wound infections
203 which become septicaemic (e.g. Mouzopoulos et al., 2008). The onset of
204 symptoms is often abrupt, with a rapid progression to septic shock and thus death
205 despite the intervention of antibiotics, typically doxycycline (Haq and Dayal,
206 2005). In the USA, *V. vulnificus* has been regarded as being responsible for most
207 of the seafood-related deaths since the first report in 1979 (e.g. Oliver, 2005).
208 Indeed, a regular source of infection with the pathogen is the consumption of
209 contaminated raw seafood, notably molluscs (e.g. Drake et al., 2007). Specifically

within Louisiana, USA during 1980-2004, 252 cases of *V. vulnificus* infection were reported of which 116 cases followed consumption of crabs (Barton and Ratard, 2006). In Japan between 1999 and 2003, 94 cases were reported in June to November but not at all in winter among 1045 hospitals, albeit with a mortality rate of 75% among those with sepsis (Inoue et al., 2008). With the more serious cases, patients often have underlying problems such as lymphocytic leukaemia and hypogammaglobulinaemia (Barton and Ratard, 2006), immunosuppression, diabetes and kidney disease (Kuo et al., 2007), liver disease (including alcohol related cirrhosis) and secondary skin lesions (cellulitis, oedema and haemorrhagic bulla) (e.g. Miyoshi, 2006). One outcome may be the need for amputation. Thus in the case of some patients who developed necrotizing fasciitis, which is a soft tissue infection, leg amputation proceeded when the excision of diseased tissue failed to halt the infection (Mouzopoulos et al., 2008). Another patient developed osteomyelitis after excision of necrotic soft tissue failed (Mouzopoulos et al., 2008).

A link between human infections and fish developed as a result of cases in The Netherlands and Israel. However, genetic differences have been identified between eel and human isolates (Wang et al., 2008). In one case in The Netherlands, a 63-year old man was hospitalized with severe pain in his right arm, which became progressively swollen (Veenstra et al., 1992). Also, there were small wounds on his hands. In hospital, the patient deteriorated with widespread skin and muscle necrosis, leading to surgery, which removed the diseased tissue. *V. vulnificus* was isolated from the blood, and determined to resemble a culture recovered previously from eels in a Dutch eel farm (Veenstra et al., 1992).

235 Eventually the patient recovered. Apparently, the day before the onset of
236 symptoms, he had cleaned eels, which had been purchased from a local market. It
237 was thought likely that the man became infected from the eels through open
238 wounds on his hand. The second example concerns a major outbreak that
239 developed in Israeli fish market workers in 1996, and was considered to reflect
240 possible climate change insofar as the period coincided with the hottest ever
241 recorded summer, temperatures (Paz et al., 2007). In fact, the outbreak started 25-
242 30 days after the hottest temperatures had occurred, and concern was expressed
243 that high water temperatures might have led to the emergence of the disease (Paz
244 et al., 2007).
245
246 Because of the serious nature of human disease attributed to *V. vulnificus,* a
247 great deal of attention has focused on understanding the pathogenicity
248 mechanisms. It has been determined that isolates produce a range of pathogenicity
249 factors including a polysaccharide capsule, haemolysin, type IV pili and various
250 proteases, principally a serine protease (Wang et al., 2008) and a 45 kDa
251 metalloprotease, which is regulated through quorum sensing more efficiently at
252 25^{o}C rather than 37^{o}C [this protease may therefore be produced mostly in
253 interstitial tissues in the limbs which have lower temperature than the rest of the
254 body], may well be responsible for skin lesions (Shinoda, 2005; Miyoshi, 2006).
255 Purified preparations of the metalloprotease enhance vascular permeability and
256 induces haemorrhaging through digestion of vascular basement membranes
257 (Miyoshi, 2006). The metalloprotease degrades a number of complex
258 macromolecules, including elastin, fibrinogen and plasma proteinase inhibitors of
259 complement (Shinoda, 2005). Compared to an environmental isolate, a

pathogenic culture led to higher cytotoxicity and a concomitant reduction in the number of macrophages in mice during the early stage of infection (Tsuchiya et al., 2007).

3. Lower risk organisms

3.1. *Grimontia hollisae*

There is limited information pointing to a role for *G. hollisae* in fish pathology. Specifically, the organism has been recovered from amberjack *(Seriola dumerili*) with vibriosis, i.e. haemorrhagic septicaemia (Ji et al., 2008). Moreover, the organism is occasionally associated in humans with moderate to severe gastro-enteritis linked to the consumption of raw shellfish (Abbott and Janda, 1994). One case led to hypotension and acute kidney failure (Hinestrosa et al., 2007). An even less common occurrence in humans is sepsis (Abbott and Janda, 1994). There is scant information on the pathogenicity mechanism in humans, with the data emphasizing aerobactin which is produced in response to iron starvation (Suzuki et al., 20060

3.2. *Photobacterium damselae* subsp. *damselae*

P. damselae subsp. *damselae* (= *V. damsela)* was recovered initially from ulcers on the pectoral fin and caudal peduncle of the damselfish, blacksmith *(Chromis punctipinnis)* (Love et al., 1981). The fish were caught in the coastal waters of southern California, USA during August to October, and at Ship Rock, Catalina Island during June to October (Love et al., 1981). This suggests a seasonal distribution in the disease, possibly coinciding with warmer water temperatures and lowered resistance resulting from physiological changes in the

285 host during sexual maturity. The ulcers, which occur particularly in the region of
286 the pectoral fin and caudal peduncle, may reach 5-20 mm in diameter (Love et al.,
287 1981). Histopathology points to the presence of granulomatous ulcerative
288 dermatitis. Subsequently, the organism was recovered from a wide range of other
289 marine animals, including sharks, turbot (*Scophthalmus maximus*), yellowtail
290 (*Seriola quinqueradiata*) and red banded sea bream *(Pagrus auriga)* (see Austin
291 and Austin, 2007). Pathogenicity was confirmed with infectivity experiments
292 using blacksmith in which 4-6 scales were removed, the dermis scarified, and the
293 wound swabbed with 10^7-10^8 viable cells of *P. damselae* subsp. *damselae.* At
294 water temperatures of 16.0-16.5^{o}C, the infected fish developed large ulcers within
295 3 days, with death following one day later (Love et al., 1981). In terms of
296 pathogenic mechanisms, a neurotoxic acetylcholinesterase has been described
297 (Pérez et al., 1998). Also, extracellular products (ECPs) with low proteolytic
298 activity have been implicated with cytotoxicity, with the LD_{50} dose ranging from
299 0.02-0.43 µg of protein g^{-1} of fish with mortalities occurring 4 and 72 h later (Fouz
300 et al., 1993). In addition, a siderophore-mediated iron sequestering system is
301 thought to be involved in pathogenicity (Fouz et al., 1997).
302
303 The role in human disease stems from the recovery of the organism from
304 wound infections (Love et al., 1981).
305
306 **3.3 *Vibrio alginolyticus***
307 *V. alginolyticus* is pathogenic to fin- and shellfish. In finfish, the organism
308 causes septicaemia in sea bream (*Sparus aurata*), exophthalmia and corneal
309 opaqueness in grouper (*Epinephelus malabaricus*), ascites, lethargy and melanosis

310 in cobia *(Rachycentrib canadum*), and ulcers (see Austin and Austin, 2007). Also,
311 *V. alginolyticus* has caused large-scale mortalities in silver sea bream *(Sparus*
312 *sarba)* in Hong Kong, gilt-head sea bream (*Sparus aurata*) in Spain, cultured
313 black sea bream (*Mylio macrocephalus*) fry in Japan and cobia (se Austin and
314 Austin, 2007). Indeed, Liu et al. (2004) calculated the LD_{50} as 3.28 x 10^4 for
315 cobia, and Lee (1995) described an ECP, which was lethal at 0.52 μg g^{-1} of fish,
316 and contained a 44 kDa toxic protease with a minimum lethal dose of 0.17 μg g^{-1}
317 of fish. ECP, with haemolytic and proteolytic activity, led to an effect on hepatic
318 heat shock protein (Deane et al., 2004). A divalent vaccine containing formalized
319 cells and ECP of *V. alginolyticus* has been developed (Moriñigo et al., 2002).
320
321 *V. alginolyticus* has been associated with shell disease and white spot in shrimp,
322 *Penaeus monodon,* in India and Taiwan, with necrosis in *Macrobrachium*
323 *rosenbergii* larvae in India, and with mass mortalities in carpet shell clam
324 *(Ruditapes decussates)* larvae in Spain (e.g. Lee et al., 1996; Selvin and Lipton,
325 2003). With white spot, the diseased shrimp developed a reddish colour and
326 displayed white spots in the cuticle (Selvin and Lipton, 2003). Isolates have been
327 reported to cause mortalities when administered to shrimp, with the LD_{50}
328 calculated variously as 1.13 x 10^5 g^{-1} (Lee et al., 1996) and 5 x 10^6 colony forming
329 units (CFU) $animal^{-1}$ (Selvin and Lipton, 2003).
330
331 In humans, *V. alginolyticus* has been implicated with ear, soft tissue and wound
332 infections, of which antibiotic-resistance has been cited as a major issue (Horii et
333 al., 2005). In Denmark from 1987-1992, *V. alginolyticus* was recovered from 17

patients with mild ear infections, all of whom had been exposed previously to seawater (Hornstrup and Gahrnhansen, 1993).

3.4. *Vibrio fluvialis*

V. fluvialis-like bacteria, which were identified biochemically and by pulsed field gel electrophoresis, have been implicated as the cause of limp lobster disease of the American lobster, *Homarus americanus* (Tall et al., 2003) and pustule disease of abalone *(Haliotis discus hannai Ino)* in P.R. China (Dalian coast) (Li et al., 1998). With this condition, several sites and different growth stages of the animals were affected with 50-60% mortalities (Li et al., 1998). Experimental infectivity experiments pointed to transmission through lesions in the abalone foot with disease developing rapidly after intramuscular injection (Li et al., 1998).

An outbreak of food poisoning in India leading to gastro-enteritis during 1981 has been blamed on *V. fluvialis* insofar as the stools of 9/14 stool samples revealed the presence of the organism (Thekdi et al., 1990). Also, the taxon has been reported as a cause of wound infection leading to haemorrhagic cellulitis and cerebritis with the source considered being multiple fire-ant stings and wading in brackish water (Huang and Hsu, 2005).

3.5. *Vibrio furnissii*

V. furnissii has been associated albeit tenuously with eel disease in Spain (Austin and Austin, 2007) and with mortalities in tiger shrimp *(Penaeus monodon)* (Sung et al., 2001).

359 There has been uncertainty about a role for this organism in human disease.
360 Certainly, it has been recovered from stool specimens, and has been implicated
361 with infantile diarrhoea, and diarrhoeal disease from 16 patients in Brazil (e.g.
362 Magalhaes et al., 1993) and during a cholera surveillance programme in Peru
363 during 1994 (Dalsgaard et al., 1997). The Brazilian isolates were haemolytic and
364 ECPs damaged HeLa cells pointing to the presence of cytolysins (Magalhaes et al.,
365 1993). Phosphomannomutase (PPM) has been linked to significant intestinal
366 damage within 3-days in mice following oral uptake. In contrast, PPM deficient
367 mutants led to reduced virulence, loss of O-antigen and reduced serum resistance
368 (Kim et al., 2003).
369
370 **3.6. *Vibrio harveyi (= V. carchariae)***
371 An organism named as *V. carchariae* was originally recovered from a dead
372 sandbar shark (*Carcharhinus plumbeus)* with vasculitis, which died at the National
373 Aquarium in Baltimore, USA, in 1982 (Grimes et al., 1984). Infected animals
374 became lethargic, inappetant, were disorientated, and developed necrotic
375 subdermal cysts. Postmortem examination revealed encephalitis, meningitis,
376 kidney necrosis, vasculitis, and unspecified liver and spleen damage. Other
377 isolations were from lemon sharks (*Negraprion brevirostris)* and from gastro-
378 enteritis and heavy mortalities in grouper (*Epinephelus coioides*). A similar
379 organism was isolated from a chronic skin ulcer on a shark (see Austin and Austin,
380 2007).
381
382 In a separate development, *V. harveyi* was recovered from opaque white
383 corneas leading to blindness in common snook *(Centropomus undecimalis)* within

384 24 h of capture in Florida, USA (Kraxberger-Beatty et al., 1990). In jack crevalle
385 (*Caranx hippos),* deep dermal lesions but not any internal damage were observed
386 in wild specimens also from Florida (Kraxberger-Beatty et al., 1990). Meanwhile,
387 Saeed (1995) attributed *V. harveyi* with mortalities in cultured brown spotted
388 grouper *(Epinephelus tauvina)* and silvery black porgy *(Acanthopagrus cuvieri)* in
389 Kuwait. Then, DNA:DNA hybridization led Ishimaru and Muroga (1997) to
390 realize that pathogenic vibrios recovered from milkfish in Japan were also *V.*
391 *harveyi.* Moreover, the organism was recovered from eye lesions in the short
392 sunfish *(Mola mola*) in Spain (Hispano et al., 1997), with the reason attributed to
393 the biting behaviour of other fish. In addition, *V. harveyi* has been involved with
394 flounder infectious necrotizing enteritis, in which the abdomen becomes distended
395 and filled with opaque fluid. There was necrosis of the posterior intestine,
396 reddening around the anus, lethargy and inappetance in farmed summer flounder
397 in Rhode Island, USA (Gauger et al., 2006). Also, skin ulcers and haemorrhaging
398 around the mouth and fins was noted in sole *(Solea senegalensis)* in Spain
399 (Zorrilla et al., 2003). The organism has been linked with infectious gastro-
400 enteritis (swollen intestine containing yellow fluid) in cultured red drum
401 *(Sciaenops ocelatus)* from Taiwan (Liu et al., 2003).
402
403 *V. harveyi* has developed into a serious pathogen of penaeids, being associated
404 with luminous vibriosis, in which the affected shrimp glow in the dark, and *Bolitas*
405 *negricans* involving the blockage of the digestive gland with balls of tissue
406 (Austin and Zhang, 2006). The organism has been reported to be a factor in loose
407 shell syndrome and white gut disease in *Penaeus monodon* in India (Jayasree et
408 al., 2006).

409

410 Pedersen et al. (1998) deduced that *V. carchariae* was a junior synonym of *V.*
411 *harveyi,* which was confirmed by Gauger and Gómez-Chairri (2002) from the
412 results of 16S rDNA sequencing. Moreover, a disease, resembling vibriosis and
413 equated to a new species, i.e. *V. trachuri,* occurred in Japanese horse mackerel
414 *(Trachurus japonicus)* especially during summer when the seawater temperature
415 exceeded 25^{o}C (Iwamoto et al., 1995). Infected fish swam erratically, developed
416 melanosis, and developed bilateral exophthalmia and internal haemorrhages.
417 However, the organism is now recognised as synonym of *V. harveyi* (Thompson et
418 al., 2002).

419

420 Certainly because of its importance in aquaculture, emphasis has been placed
421 on improving diagnostics. In this connection, a polymerase chain reaction (PCR)
422 using the *toxR* gene enabled detection of 4.0 x 10^3 cells ml^{-1} (including cells
423 within diseased tissues) in <5 h, but not of other vibrios (Pang et al., 2006).

424

425 Prevention of *V. harveyi* infections by vaccination has met with some success.
426 Thus, a bivalent vaccine (with *P. damselae* subsp. *piscicida)* comprising
427 formalized cells and ECP administered by immersion with booster by
428 intraperitoneal injection led to high levels of protection (relative percent protection
429 [RPS] = ~88%) for 4 months (Arijo et al., 2005).

430

431 In terms of human disease, *V. harveyi (= V. carchariae)* has been recovered
432 from wound infections, specifically from a leg wound resulting from a shark bite
433 in South Carolina, USA (Pavia et al., 1989).

3.7. *Vibrio metschnikovii*

V. metschnikovii is regarded as potentially pathogenic to larval giant clams, *Tridacna gigas* with infection leading to general disintegration of the tissues and total mortality after exposure to 10^7 bacteria ml^{-1} (Sutton and Garrick, 1993). The organism has been recovered from raw fish and shellfish in markets and shops, and is deemed to pose a risk to human health (Buck, 1991) with pathogenic factors reflecting the presence of haemolysins and verotoxins (Matte et al., 2007).

3.8. *Vibrio mimicus*

V. mimicus has been considered as a secondary invader of red claw crayfish (*Cherax quadricarinatus*), which were weakened by poor management, overcrowding and/or adverse water quality (Eaves and Ketterer, 1994). The association with human illness is in connection with food borne infections leading to gastro-enteritis and diarrhoea in which an enterotoxic haemolysin is produced that targets intestinal epithelia cells effecting ion transport (Takahashi et al., 2007; Mizuno et al., 2009).

4. Future perspectives

New pathogenic *Vibrio* species are frequently described. Therefore, the range of zoonotic organisms may well increase. Diagnosticians need to be vigilant and aware of this possibility. Certainly, the seriousness of *V. vulnificus* as a pathogen of both aquatic animals and humans cannot be overstated, and the number of cases of disease attributed to this organism seems likely to grow. The involvement of vibrios with disease has prompted excellent work particularly in the realms of

459 ecology, pathogenicity and disease control strategies; this trend may be expected
460 to continue.
461
462 **5. Conflict of Interest Statement**
463 The author does not have any conflict of interest. The views expressed in the
464 article are those of the author, and they have not been influenced by any
465 external interest.
466
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Table 1

Differential characteristics of zoonotic vibrios and their association with human and animal diseases (based on Farmer et al., 2005).

Characteristic:	*G. hollisae*	*P. damselae* subsp. *damselae*	*V. alginolyticus*	*V. harveyi*	*V. cholerae*	*V. fluvialis*	*V. furnissii*	*V. metschnikovii*	*V. mimicus*	*V. parahaemolyticus*	*V. vulnificus*
Oxidase production	+	+	+	+	+	+	+	-	+	+	(+)
Arginine dihydrolase	-	+	-	-	-	+	+	D	-	-	-
Lysine decarboxylase	-	D	+	+	+	-	-	-	+	+	+
Gas from glucose	-	+	-	-	-	-	+	-	-	-	-
Indole production	+	-	+	+	+	D	-	-	+	+	+
Voges	-	(+)	(+)	-	+	-	-	+	-	-	-

Proskauer reaction											
Utilization of cellobiose	-	-	-	+	-	D	D	-	-	-	(+)
Growth in 0% NaCl	-	-	-	-	+	+	+	-	+	-	-
Growth in 0.3% NaCl	-	D	-	-	+	+	+	+	+	-	+
Growth in 12% NaCl	-	-	+	-	-	-	(-)	-	-	-	-
Cause of wound infections in humans		+	+	+		+					+
Cause of gastro-intestinal	+				+	+	+	+	+	+	+

disease in humans																				
Cause of fish disease	+		+		+		+		+				+					+		+
Cause of invertebrate disease				+		+		(+)		+				+		+		+		+

+, - and D correspond to 100%, 0% and 21-79% of positive results, respectively. (+) and (-) correspond to ≥80% and ≤20% of positive results.