

INFECTION WITH WHITE SPOT SYNDROME VIRUS

1. Scope

Infection with white spot syndrome virus means infection with the pathogenic agent white spot syndrome virus (WSSV), Genus *Whispovirus*, Family *Nimaviridae*.

2. Disease information

2.1. Agent factors

2.1.1. Aetiological agent, agent strains

WSSV was assigned by the International Committee on Taxonomy of Viruses (ICTV) as the only member of the genus *Whispovirus* within the *Nimaviridae* family. Virions of WSSV are ovoid or ellipsoid to bacilliform in shape, have a regular symmetry, and measure 80–120 nm in diameter and 250–380 nm in length. A flagella-like extension (appendage) may be observed at one end of the virion. Today, although various geographical isolates with genotypic variability have been identified, they are all classified as a single species (white spot syndrome virus) within the genus *Whispovirus* (Lo *et al.*, 2012).

2.1.2. Survival outside the host

The agent is viable for at least 30 days at 30°C in seawater under laboratory conditions (Momoyama *et al.*, 1998); and is viable in ponds for at least 3–4 days (Nakano *et al.*, 1998). Laboratory emulations of drainable and non-drainable ponds suggest that the virus is no longer infective after 21 days of sun-drying or after 40 days in waterlogged pond sediment (Satheesh Kumar *et al.*, 2013).

2.1.3. Stability of the agent (effective inactivation methods)

The agent is inactivated in <120 minutes at 50°C and <1 minute at 60°C (Nakano *et al.*, 1998).

In laboratory studies, WSSV was inactivated under following conditions:

Heat: 55°C for 90 minutes, 70°C for 5 minutes (Chang *et al.*, 1998); 50°C for 60 minutes; 60°C for 1 minute; 70°C for 0.2 minutes (Nakano *et al.*, 1998).

Desiccation: WSSV adsorbed onto the filter paper and allowed to dry subsequently was inactivated in 1 hour at 30°C and in 3 hours at 26°C (Maeda *et al.*, 1998, Nakano *et al.*, 1998).

pH: pH 3 for 60 minutes; pH 12 for 10 minutes (Chang *et al.*, 1998, Balasubramanian *et al.*, 2006).

Ultraviolet light: Total dose of 9.30×10^5 $\mu\text{Ws}/\text{cm}^2$ (Chang *et al.*, 1998).

Ozone: Total residual oxidants concentration of 0.5 $\mu\text{g ml}^{-1}$ for 10 minutes (Chang *et al.*, 1998).

Sodium hypochlorite: Total free chlorine concentration of 100 ppm for 10 minutes (Chang *et al.*, 1998).

Benzalkonium chloride: 100 ppm for 10 minutes (Balasubramanian *et al.*, 2006).

Iodophore: Total free iodine concentration of 100 ppm for 10 minutes (Chang *et al.*, 1998).

2.1.4. Life cycle

In-vitro studies with primary cell culture and *in-vivo* studies with postlarvae (PL) show that the replication cycle is approximately 20 hours at 25°C (Chang *et al.*, 1996; Chen *et al.*, 2011; Wang *et al.*, 2000).

2.2. Host factors

The virus can infect a wide range of aquatic crustaceans especially decapods, including marine, brackish and freshwater prawns, crabs, crayfish and lobsters (Maeda *et al.*, 2000).

2.2.1. Susceptible host species

Of all of the species that have been tested to date, no decapod (order Decapoda) crustacean from marine and brackish or freshwater sources has been reported to be refractory to infection with WSSV (Flegel, 1997; Lightner, 1996; Lo & Kou, 1998; Maeda *et al.*, 2000; Stentiford *et al.*, 2009).

2.2.2. Susceptible stages of the host

All life stages are potentially susceptible, from eggs to broodstock (Lightner, 1996; Venegas *et al.*, 1999). WSSV genetic material has been detected in reproductive organs (Lo *et al.*, 1997), but susceptibility of the gametes to WSSV infection has not been determined definitively.

2.2.3. Species or subpopulation predilection (probability of detection)

The best life stages of crustaceans for detection of WSSV are late PL stages, juveniles and adults. Probability of detection can be increased by exposure to stressful conditions (e.g. eye-stalk ablation, spawning, moulting, changes in salinity, temperature or pH, and during plankton blooms).

2.2.4. Target organs and infected tissue

The major target tissues of WSSV are of ectodermal and mesodermal embryonic origin, especially the cuticular epithelium and subcuticular connective tissues (Momoyama *et al.*, 1994; Wongteerasupaya *et al.*, 1995). Although WSSV infects the underlying connective tissue in the crustacean hepatopancreas and midgut, the tubular epithelial cells of these two organs are of endodermal origin, and they do not become infected.

2.2.5. Persistent infection

Many decapod species have been shown to be subclinically infected with WSSV and are thought to be carriers (Lo & Kou, 1998).

2.2.6. Vectors

The virus can be transmitted directly from host to host without the need for a biological vector.

2.2.7. Known or suspected wild aquatic animal carriers

Wild decapods known to be reservoirs of infection with WSSV include *Mysis* sp. (Huang *et al.*, 1995), *Acetes* sp., *Alpheus* sp., *Callinassa* sp., *Exopalaemon* sp., *Helice* sp., *Hemigrapsus* sp., *Macrophthalmus* sp., *Macrophthel* sp., *Metaplex* sp., *Orithyia* sp., *Palaemonoidea* sp., *Scylla* sp., *Sesarma* sp., *Stomatopoda* sp. and (He & Zhou, 1996; Lei *et al.*, 2002). These species can express the disease under suitable environmental conditions. However, non-decapodal crustaceans, such as copepods (Huang *et al.*, 1995), rotifers (Yan *et al.*, 2004), *Balanus* sp. (Lei *et al.*, 2002), and *Tachypleidue* sp. (He & Zhou, 1996) may be apparently healthy carrier animals. There is inconclusive evidence for the WSSV carrier status of *Artemia salina* (Chang *et al.*, 2002). Other marine molluscs, polychaete worms (Vijayan *et al.*, 2005), as well as non-crustacean aquatic arthropods such as sea slaters (*Isopoda*) and Euphydradae insect larvae can mechanically carry the virus without evidence of infection (Lo & Kou, 1998).

2.3. Disease pattern

Infection with WSSV sometimes causes clinical disease (Tsai *et al.*, 1999), depending on factors as yet poorly understood but related to species tolerance and environmental triggers. With an appropriate infection dose to allow sufficient time before mortality, animals susceptible to disease show large numbers of virions circulating in the haemolymph (Lo *et al.*, 1997), but this may also occur for tolerant species that show no mortality. Thus, high viral loads *per se* do not cause disease or mortality for all susceptible species.

2.3.1. Transmission mechanisms

The infection with WSSV can be transmitted horizontally by consumption of infected tissue (e.g. cannibalism, predation, etc.), and by water-borne routes. Transmission of WSSV can occur from apparently healthy animals in the absence of disease. Dead and moribund animals can be a source of disease transmission (Lo & Kou, 1998).

True vertical transmission (intra-ovum) of WSSV to the progeny has not been demonstrated.

2.3.2. Prevalence

Prevalence of infection with WSSV is highly variable, from <1% in infected wild populations to up to 100% in captive populations (Lo & Kou, 1998).

2.3.3. Geographical distribution

Infection with WSSV has been identified from crustaceans in China (People's Rep. of), Japan, Korea (Rep. of), South-East Asia, South Asia, the Indian Continent, the Mediterranean (Stentiford & Lightner,

2011), the Middle East, and the Americas. Zones and compartments free from infection with WSSV are known within these regions (Lo *et al.*, 2012).

2.3.4. Mortality and morbidity

All penaeid shrimp species are highly susceptible to infection with WSSV, often resulting in high mortality. Crabs, crayfish, freshwater prawns, spiny lobsters and clawed lobsters are susceptible to infection with WSSV, but morbidity and mortality as a consequence of infection are highly variable (Lo & Kou, 1998). High level infections with WSSV are known in some decapods in the absence of clinical disease.

2.3.5. Environmental factors

Disease outbreaks may be induced by stressors, such as rapid changes in salinity. Water temperature has a profound effect on disease expression, with average water temperatures of between 18 and 30°C being conducive to WSSV outbreaks (Song *et al.*, 1996; Vidal *et al.*, 2001). Under experimental challenge condition, WSSV-induced mortality in shrimp is reduced when the temperature increases above 32°C (Vidal *et al.*, 2001).

2.4. Control and prevention

Although the underlying mechanism remains unknown, laboratory experiments have shown that 'vaccinated' shrimp and crayfish have better survival rates after WSSV challenge. It was first shown that *Penaeus japonicus* shrimp that survived natural and experimental WSSV infections displayed resistance to subsequent challenge with WSSV (Venegas *et al.*, 2000). Later studies showed that intramuscular injection of inactivated WSSV virions or recombinant structural protein, (VP28), provided shrimp with some protection against experimental WSSV infection. Furthermore, shrimp fed with food pellets coated with inactivated bacteria over-expressing VP28 showed better survival rates after WSSV challenge (Witteveldt *et al.*, 2004). However, although these results seemed promising, the protection was effective only when the shrimp were infected with a low dosage of WSSV. Also, the effect usually lasted for only a few days, or in the case of crayfish, for about 20 days. Another potential means of protecting shrimp against infection with WSSV is to use RNA interference (RNAi). WSSV gene-specific double-stranded (ds) RNAs produced strong anti-WSSV activity, protecting the shrimp against infection with WSSV, but the same study showed that long dsRNA induced both sequence-dependent and independent anti-viral responses in shrimp (Robalino *et al.*, 2005). A more recent study showed that even oral administration of bacterially expressed VP28 dsRNA could protect shrimp against infection with WSSV (Sarathi *et al.*, 2008). However, although dsRNA technology continues to be explored, there are still no field trial data for either the vaccination or the RNAi approach.

2.4.1. Vaccination

No consistently effective vaccination methods have been developed for infection with WSSV.

2.4.2. Chemotherapy

No published or validated methods.

2.4.3. Immunostimulation

Several reports have shown that beta-glucan, vitamin C, seaweed extracts (fucoidan) and other immunostimulants may improve resistance to infection with WSSV (Chang *et al.*, 2003; Chotigeat *et al.*, 2004).

2.4.4. Resistance breeding

Progress in breeding *P. vannamei* for resistance to infections with WSSV has been reported (Cuéllar-Anjel *et al.*, 2012; Huang *et al.*, 2012).

2.4.5. Restocking with resistant species

Not applicable for infection with WSSV.

2.4.6. Blocking agents

There are no efficient blocking agents that can be recommended at this time. rVP28 has an effect, but it cannot yet be used as a practical blocking agent.

2.4.7. Disinfection of eggs and larvae

For transovum transmission, disinfection of egg is likely to be effective (Lo & Kou, 1998), but this has not yet been confirmed in formal scientific trials.

2.4.8. General husbandry practices

A number of husbandry practices have been used successfully to manage infection with WSSV, such as avoiding stocking in the cold season, use of specific pathogen free (SPF) or polymerase chain reaction (PCR)-negative seed stocks, use of biosecure water and culture systems (Withyachumnarnkul, 1999) and polyculture of shrimp and fish (He *et al.*, unpublished data).

3. Sampling

3.1. Selection of individual specimens

Samples of moribund shrimp or shrimp that show clinical signs (see Section 4.1.1) or exhibit behavioural changes (Section 4.1.2) should be selected for detection of WSSV.

3.2. Preservation of samples for submission

See Chapter 2.2.0 *General information* (for diseases of crustaceans) for guidance on preservation of samples for the intended test method.

3.3. Pooling of samples

The effect of pooling on diagnostic sensitivity has not been evaluated, therefore larger life stages should be processed and tested individually. However, it may be necessary to pool small life stages, for example PL, to obtain sufficient material for nucleic acid extraction and molecular testing.

3.4. Best organs or tissues

Tissue tropism analysis from both experimentally infected shrimp and wild-captured brooders shows that tissues originating from the ectoderm and mesoderm, especially the cuticular epithelium and subcuticular connective tissues, as well as other target tissues (e.g. antennal gland, haematopoietic organ, etc.), are the main target tissues for infection with WSSV. Samples of or from the pleopods, gills, haemolymph, stomach or abdominal muscle are recommended for submission (Lo *et al.*, 1997).

For non-lethal sampling and screening by PCR, gill, haemolymph or pleopod are suitable tissues.

Please see Section 4.3.1.2.4.1 for details of the sample procedure.

3.5. Samples/tissues that are not suitable

Although WSSV infects the underlying connective tissue in the shrimp hepatopancreas and midgut, the columnar epithelial cells of these two organs are of endodermal embryonic origin (Lo *et al.*, 1997), and they are not appropriate tissues for detection. The compound eye may contain a PCR inhibitor (Lo *et al.*, 1997) and it is therefore not suitable for PCR-based diagnosis.

4. Diagnostic methods

4.1. Field diagnostic methods

4.1.1. Clinical signs

White spots embedded within the exoskeleton are the most commonly observed clinical sign. In most shrimp, these spots range from barely visible to 3 mm in diameter, and they sometimes coalesce into larger plates. However, it should be noted that environmental stress factors, such as high alkalinity, or bacterial disease can also cause white spots on the carapace of shrimp, and that moribund shrimp with infection with WSSV may have few, if any, white spots. Therefore, the appearance of white spots is not a reliable diagnostic sign of infection with WSSV infection. High degrees of colour variation with a predominance of reddish or pinkish discoloured shrimp are seen in diseased populations.

WSSV infections can be subclinical or manifest as clinical disease. The penaeid shrimp in aquaculture will generally show clinical signs associated with high morbidity and mortality. Some animals may die without showing any clinical signs. Non-penaeid species (e.g. crab, lobster) generally have subclinical infections under natural conditions.

4.1.2. Behavioural changes

The affected animals can show lethargy, decreased or absent feed consumption and abnormal swimming behaviour – slow swimming, swimming on side, swimming near water surface and gathering around edges of rearing units (Corbel *et al.*, 2001; Sahul Hameed *et al.*, 1998; 2001). A very high mortality rate in the shrimp population can be expected within a few days of the onset of behavioural signs.

4.2. Clinical methods

4.2.1. Gross pathology

In addition to the clinical and behavioural signs in Section 4.1.1 and 4.1.2 above, the following gross pathology has been reported in clinically affected penaeid shrimp: loosened attachment of the carapace with underlying cuticular epithelium (Sánchez-Paz, 2010), so carapace can be easily removed (Zhan *et al.*, 1998); empty gastro-intestinal tract due to anorexia (Escobedo-Bonilla, 2008); delayed clotting of haemolymph (Heidarieh, 2013); excessive fouling of gills (Wu *et al.*, 2013) and exoskeleton.

4.2.2. Clinical chemistry

Haemolymph withdrawn from WSSV-infected shrimp always has a delayed (or sometimes completely absent) clotting reaction.

4.2.3. Microscopic pathology

4.2.3.1. Wet mounts

Demonstration of hypertrophied nuclei in squash preparations of the gills and/or cuticular epithelium, which may be stained or unstained.

4.2.3.1.1 T-E staining

A T-E staining solution may be prepared from Trypan blue 0.6%, Eosin Y 0.2%, NaCl 0.5%, phenol 0.5%, and glycerol 20% (Huang & Yu, 1995) and used as follows:

- i) Place a piece of lesion tissue (e.g. a piece of gill or stomach epithelium without the cuticle) on a slide and mince with a scalpel.
- ii) Add 1–2 drops of the T-E staining solution to the minced tissue, mix and allow to stain for 3–5 minutes.
- iii) Lay a cover glass over the stained tissue and cover with several pieces of absorbent paper. Use a thumb to squash the mince into a single layer of cells.

If the sample was taken from a heavily infected shrimp, it should be easy to see the hypertrophied nuclei and intranuclear eosinophilic or vacuolation-like inclusion bodies under a 400–1000× light microscope.

4.2.3.2. Smears

Demonstration of aggregates of WSSV virions in unstained smear preparations of haemolymph by dark-field microscopy.

NOTE: This is the simplest of the microscopic techniques and is recommended for people with limited expertise in diagnosing infection with WSSV. The aggregates appear as small reflective spots of 0.5 µm in diameter (Momoyama *et al.*, 1995).

4.2.3.3. Fixed sections

Histological changes commonly reported in susceptible species include: Hypertrophied nuclei with marginated chromatin material in virus-infected cells; eosinophilic to pale basophilic (with haematoxylin & eosin stain) stained intranuclear viral inclusions within hypertrophied nuclei and multifocal necrosis associated with pyknotic and karyorrhectic nuclei in affected tissues of ectodermal and mesodermal origin. The infection with infectious hypodermal and hematopoietic necrosis virus, another DNA virus, produces similar inclusions that need to be differentiated from those of WSSV.

4.2.3.4. In-situ hybridisation

Use of WSSV-specific DNA probes with histological sections to demonstrate the presence of WSSV nuclei acid in infected cells.

4.2.3.5. Immunohistochemistry

Use of WSSV-specific antibodies with histological sections or wet mounts to demonstrate the presence of WSSV antigen in infected cells.

4.2.4. Electron microscopy/cytopathology

Demonstration of the virus in tissue sections or in semi-purified negatively stained virus preparations (e.g. from haemolymph). See Section 2.1.1 for virion morphology.

4.3. Agent detection and identification methods

4.3.1. Direct detection methods

Not reported.

4.3.1.1. Microscopic methods

See Section 4.2.3 above.

4.3.1.1.1. Wet mounts

See Section 4.2.3.1 above.

4.3.1.1.2. Smears

See Section 4.2.3.2 above.

4.3.1.1.3. Fixed sections

See Section 4.2.3.3 above.

4.3.1.2. Agent isolation and identification

4.3.1.2.1. Bioassay method

If SPF shrimp are available, the following bioassay method is based on Nunan *et al.* (1998) and Durand *et al.* (2000), is suitable for WSSV diagnosis.

- i) For bioassay, remove the pleopods from shrimp suspected of being infected with WSSV and homogenise in TN buffer (0.02 M Tris/HCl, 0.4 M NaCl, pH 7.4).
- ii) Following centrifugation at 1000 *g* for 10 minutes, dilute the supernatant fluid 1/10 with 2% NaCl and filter (0.2 µm filter)
- iii) Inject 0.2 ml of inoculum into the dorso-lateral aspect of the fourth abdominal segment of indicator shrimp (e.g. SPF *P. vannamei* at the juvenile stage), injecting between the tergal plates into the muscle of the third abdominal segment.
- iv) Examine moribund shrimp grossly or by using the methods described above. If at 3–5 days after inoculation there are still no moribund shrimp and all test results are negative, then it is safe to conclude that the bioassay results are negative.

4.3.1.2.2. Cell culture/artificial media

WSSV can be isolated from primary cultures of lymphoid or ovary cells. However, it is NOT recommended to use cell culture as a routine isolation method because of: 1) the high risk of contamination, and, 2) the composition of the medium varies depending on the tissue type, host species and experimental purpose; that is, to date there is no standard or recognised medium that can be recommended. As primary cell culture is so difficult to initiate and maintain for virus isolation purposes, bioassay should be the primary means for virus propagation

4.3.1.2.3. Antibody-based antigen detection methods

Both polyclonal and monoclonal antibodies raised against either the virus or a recombinant viral structural protein have been used in various immunological assays including western blot analysis, immunodot assay, indirect fluorescent antibody test (IFAT), immunohistochemistry (IHC) or enzyme-linked immunosorbent assay (ELISA) to detect WSSV (Huang *et al.*, 1995; Poulos *et al.*, 2001; Sithigorngul *et al.*, 2006; Yoganandhan *et al.*, 2004). Antibody-based methods can be fast,

convenient and applicable to field use, but as they have only about the same sensitivity as 1-step PCR, they are recommended only to confirm acute infection with WSSV.

4.3.1.2.4. Molecular techniques

4.3.1.2.4.1 Polymerase chain reaction (PCR)

The PCR protocol described here is from Lo *et al.* 1996a and b, and uses sampling methods from Lo *et al.* 1997. It is recommended for all situations where infection with WSSV diagnosis is required. A positive result in the first step of this standard protocol implies a serious infection with WSSV, whereas, when a positive result is obtained in the second amplification step only, a latent or carrier-state infection is indicated. Alternative PCR assays have also been developed (e.g. Numan & Lightner, 2011), but before use they should first be compared with the protocol described here.

PCR commercial kits are available for WSSV detection and are acceptable provided they have been validated as fit for such purpose. Please consult the OIE Register for kits that have been certified by the OIE (<https://www.oie.int/en/what-we-offer/veterinary-products/#ui-id-5>).

DNA extraction

- i) Collect 100–200 mg shrimp tissue (pleopod of live juvenile to subadult shrimp, postlarvae 11 upwards [PL11 up] with removed heads, or whole PL10, or use 100 µl haemolymph) in a 1.5 ml microfuge tube with 600 µl lysis solution (100 mM NaCl, 10 mM Tris/HCl, pH 8, 25 mM EDTA [ethylene diamine tetra-acetic acid], 0.5% SLS [sodium N-laurylsarcosinate] or 2% SDS [sodium dodecyl sulphate], and 0.5 mg ml⁻¹ proteinase K added just before use). For non-destructive screening, pleopods can be removed using red-hot forceps. For this procedure, the animal should be wrapped in a wet towel such that only the organ to be excised is left exposed.
- ii) Using a disposable stick, homogenise the tissue in the tube thoroughly.
- iii) After homogenisation, incubate at 65°C for 1 hour.
- iv) Add 5 M NaCl to a final concentration of 0.7 M. Next, slowly add 1/10 volume of N-cetyl N,N,N-trimethylammonium bromide (CTAB)/NaCl solution (10% CTAB in 0.7 M NaCl) and mix thoroughly.

NOTE: In addition to the CTAB extraction method described here, commercial extraction kits are often used as part of normal surveillance activities.

- v) Incubate at 65°C for 10 minutes, and then, at room temperature, add an equal volume of chloroform/isoamyl alcohol (24/1) and mix gently. Centrifuge at 13,000 g for 5 minutes and then transfer the aqueous solution (upper layer) to a fresh 1.5 ml tube and add an equal volume of phenol.
- vi) Mix gently and centrifuge at 13,000 g for 5 minutes. Collect the upper layer solution and repeat the phenol extraction process once or twice.
- vii) Transfer the final upper layer to a new tube, mix gently with two volumes of chloroform/isoamyl alcohol (24/1) and centrifuge at 13,000 g for 5 minutes.
- viii) Transfer the upper layer to a new tube and precipitate DNA by adding two volumes of 95% or absolute ethanol followed by standing at –20°C for 30 minutes or –80°C for 15 minutes.
- ix) Centrifuge at 13,000 g for 30 minutes and discard the ethanol. Wash the DNA pellet with 70% ethanol, dry and resuspend in 100 µl sterilised double-distilled water at 65°C for 15 minutes.
- x) Use 1 µl of this DNA solution for one PCR.

Note: the following nested PCR procedures are well established and provide reliable diagnostic results under the specified conditions. Care should be taken, however, to ensure that DNA samples are prepared from the recommended organs, and that the PCR temperature is accurately applied (particularly for annealing, the recommended temperature is 55°C). To prevent the possibility of false positive results, it is important to adhere to the specified procedures, especially when they are used to test new candidate hosts such as *Cherax quadricarinatus* (Claydon *et al.*, 2004), as well as *Procambarus clarkii* (red swamp crayfish) and *Procambarus zonangulus* (Southern white river crayfish). For diagnosed incidences of infection with WSSV in a new host or in a previously free zone, DNA sequencing should be used to confirm the positive results.

First-step PCR

- i) Add 1 µl DNA template solution (containing about 0.1–0.3 µg DNA) to a PCR tube containing 100 µl of reaction mixture (10 mM Tris/HCl, pH 8.8, 50 mM KCl, 1.5 mM MgCl₂, 0.1% Triton X-100, 200 µM of each dNTP, 100 pmol of each primer, 2 units of heat-stable DNA polymerase).
- ii) The outer primer sequences are 146F1, 5'-ACT-ACT-AAC-TTC-AGC-CTA-TCTAG-3' and 146R1, 5'-TAA-TGC-GGG-TGT-AAT-GTT-CTT-ACG-A-3'.
- iii) The PCR profile is one cycle of 94°C for 4 minutes, 55°C for 1 minute, and 72°C for 2 minutes, followed by 39 cycles of 94°C for 1 minute, 55°C for 1 minute, and 72°C for 2 minutes and a final 5-minute extension at 72°C. The WSSV-specific amplicon from this reaction is 1447 bp. The sensitivity is approximately 20,000 copies of a plasmid template.

Second step of the (nested) PCR

This second step is necessary for the detection of WSSV in shrimp at the carrier stage.

- i) Add 10 µl of the first-step PCR product to 90 µl of a PCR cocktail with the same composition as above except that it contains the second (inner) primer pair: 146F2 (5'-GTA-ACT-GCC-CCT-TCC-ATC-TCC-A-3') and 146R2 (5'-TAC-GGC-AGC-TGC-TGC-ACC-TTG-T-3').
- ii) Use the same PCR amplification protocol as above. The WSSV-specific amplicon from this reaction is 941 bp. The overall sensitivity of both steps is approximately 20 copies of a WSSV plasmid template.
- iii) To visualise, electrophorese 10 µl PCR products on 1% agarose gels containing ethidium bromide at a concentration of 0.5 µg ml⁻¹.
- iv) Decapod-specific primers (143F 5'-TGC-CTT-ATC-AGCTNT-CGA-TTG-TAG-3' and 145R 5'-TTC-AGN-TTT-GCA-ACC-ATA-CTT-CCC-3' yielding an 848 bp amplicon; N represents G, A, T, or C) should be used in control reactions to verify the quality of the extracted DNA and the integrity of the PCR. In the penaeid shrimp *P. aztecus*, the PCR product generated by this decapod-specific primer pair corresponds to nucleotide sequence 352–1200 of the 18s rRNA. The decapod 18s RNA sequence is highly conserved and produces a similar sized PCR product in almost all decapods. A positive control (WSSV DNA template) and negative controls (no template and shrimp DNA template) should be included in every assay.

4.3.1.2.4.2 DNA sequencing of PCR products

The amplicon from the two-step nested diagnostic PCR should be sequenced. The cloning and sequencing protocols described here are according to Claydon *et al.* (2004).

- i) Excise the DNA fragments selected for further analysis from the agarose gels and purify them using any of the commercially available PCR clean up kits.
- ii) Faint amplicons can be cloned into vector plasmids prior to sequencing if required. Amplify and purify the recombinant plasmid for DNA sequencing.
- iii) Use suitable primers to sequence the amplicon.
- iv) Compare the sequences obtained with available databases using the Basic Local Alignment Search Tool (BLAST) to determine approximate phylogenetic affiliations.

4.3.1.2.4.3 Taqman real-time PCR method

The protocol described here is from Durand & Lightner (2002). This detection method is highly specific to WSSV, is extremely sensitive (four copies) and has a wide dynamic range (seven logs).

Construction of positive control vector and preparation of standard curve

The DNA fragment of 69 bp amplified by the forward and reverse primers (indicated below) is cloned in pGEM-T easy or other suitable vectors, and then confirmed by sequencing. The plasmid DNA is purified by any commercial plasmid extraction kits and the concentration is determined by using a spectrophotometer or other methods. The gene copy number is determined according to the molar mass derived from the plasmid DNA containing the 69 bp insert. The plasmid DNAs are then serially diluted tenfold to generate standard curves ranging from 10¹ to 10⁷ copies.

DNA extraction

DNA extraction should be performed according to the above protocol described for PCR (4.3.1.2.4.1) or by using a commercial kit. The concentration of purified DNA can be determined by spectrophotometer or by other methods.

Real-time PCR

The TaqMan assay is carried out using the TaqMan Universal PCR Master Mix, which contains AmpliTaq Gold DNA polymerase, AmpErase UNG, dNTPs with dUTP and optimised buffer components (PE Applied Biosystems, Foster City, CA, USA¹). Primer sequences are WSS1011F: 5'-TGG-TCC-CGT-CCT-CAT-CTC-AG-3', WSS1079R: 5'-GCT-GCC-TTG-CCG-GAA-ATT-A-3', Taqman Probe: 5'-AGC-CAT-GAA-GAA-TGC-CGT-CTA-TCA-CAC-A-3'.

- i) Add a sample of 10–50 ng of DNA to set up a 25 µl reaction mixture containing 0.3 µM of each primer and 0.15 µM of TaqMan probe.
- ii) The PCR profile is one cycle of 50°C for 2 minutes for AmpErase uracil-N-glycosylase (UNG) and 95°C for 10 minutes for activation of AmpliTaq, followed by 40 cycles of 95°C for 15 seconds and 60°C for 1 minute.
- iii) To determine the WSSV copy number of the extracted DNA samples, the samples are subjected to PCR reaction alongside the serially diluted plasmid DNA standard. After reaction, the software accompanying the PCR system automatically determines the Ct value for each PCR sample. Based on the Ct values, the software calculates the standard curve for standard dilution and determines the WSSV copy number for the DNA samples by extrapolating values from the standard curve.

4.3.1.2.4.4. In-situ hybridisation (ISH) method

The protocol described here is based on that developed by Nunan & Lightner (1997).

- i) Fix moribund shrimp with Davidson's AFA fixative for 24–48 hours.
- ii) Embed the tissues in paraffin and cut into 5 µm sections. Place sections on to positively charged microscope slides.
- iii) Heat the slide on a hot plate at 65°C for 30 minutes.
- iv) Deparaffinise, rehydrate and then treat for 2–30 minutes (depending on tissue type) with 100 µg ml⁻¹ proteinase K in Tris/NaCl/EDTA (TNE) buffer at 37°C.
- v) Post-fix the slides by chilling in pre-cooled 0.4% formaldehyde for 5 minutes at 4°C and wash the slides in 2 × standard saline citrate (SSC; 1 × SSC = 150 mM NaCl, 15 mM tri-sodium citrate, pH 7.0) at room temperature.
- vi) Pre-hybridise the slides with pre-hybridisation solution (50% formamide, 0.2% Ficoll 400, 0.2% polyvinylpyrrolidone, 0.2% bovine serum albumin, 5 × SSC, 1 mM EDTA, 50 mM Tris/HCl, pH 8) for 30 minutes at 42°C.
- vii) Follow with hybridisation with the 1447 bp WSSV-specific PCR amplicon (or with any other WSSV-specific PCR amplicon; see Section 4.3.1.2.3.1 "First-step PCR" above) that has been labelled with digoxigenin. It is recommended that the probe be labelled by incorporating DIG-dNTP by the PCR method. Optimum concentration should be determined by testing and adjusting until a high specific signal is obtained against a low background.
- viii) For hybridisation, boil the probe for 10 minutes and immediately place on ice. Dilute the probe to 30–50 ng ml⁻¹ in pre-hybridisation solution and apply 500 µl to each slide.
- ix) Put the slide on a hotplate at 85–95°C for 6–10 minutes (make sure that it does not reach boiling point), quench slides on ice for 5 minutes and then transfer to a humid chamber for 16–20 hours at 42°C.
- x) After hybridisation, wash the slides twice for 15 minutes each time with 2 × SSC at room temperature, twice for 5 minutes with 1 × SSC at 37°C, and twice for 5 minutes with 0.5 × SSC at 37°C.

1 Reference to specific commercial products as examples does not imply their endorsement by the OIE. This applies to all commercial products referred to in this *Aquatic Manual*.

- xi) For hybridisation detection, wash slides with maleic acid buffer (100 mM maleic acid, 150 mM NaCl, pH 7.5) for 5 minutes at room temperature.
- xii) Block the slides with blocking solution (2% normal goat serum and 0.3% Triton X-100 in maleic acid buffer) for 30 minutes at 37°C.
- xiii) Add 250 µl anti-DIG alkaline phosphatase (AP)-conjugated antibody solution (1 µl ml⁻¹ anti-DIG/AP-Fab fragment in maleic acid buffer containing 1% normal goat serum and 0.3% Triton X-100) to each slide, and incubate at 37°C for 30 minutes.
- xiv) Wash the slides twice with maleic acid buffer for 10 minutes each and once with detection buffer (100 mM Tris/HCl, 100 mM NaCl, pH 9.5) at room temperature.
- xv) Add 500 µl development solution (prepare immediately before use by adding 45 µl NBT salt solution [75 mg ml⁻¹ in 70% dimethylformamide], 35 µl 5-bromo-4-chloro-3-indoyl phosphate, toluidinum salt [X-phosphate] solution [50 mg ml⁻¹ in dimethylformamide] and 1 ml 10% PVA to 9 ml of detection buffer) to each slide and incubate in the dark in a humid chamber for 1–3 hours.
- xvi) Stop the reaction by washing the slides in TE buffer (10 mM Tris/HCl, 1 mM EDTA, pH 8.0) for 15 minutes at room temperature. Wash the slides in distilled water for ten dips, counterstain the slides in 0.5% aqueous Bismarck Brown Y for approximately 5 minutes and then rinse with water. Wet mount using aqueous mounting media for observation immediately or dehydrate the slides and mount with mounting media for long-term preservation.
- xvii) Mount the slides with cover-slips and examine with a bright field microscope. Positive hybridisation appears as a dark blue to black precipitate against the yellow to brown counterstain.

4.3.1.2.4.5. Loop-mediated isothermal amplification (LAMP) method

The protocol described here is from Kono *et al.* (2004). The LAMP method is sensitive and rapid, and it amplifies the target nucleic acids under isothermal conditions, therefore needing no sophisticated machine for thermal cycling.

DNA extraction

DNA extraction could be performed according to the above protocol described for PCR (4.3.1.2.4.1) or by other suitable methods or by commercial kits.

LAMP reaction

- i) Add DNA to a tube to set up a 25 µl reaction mixture (20 mM Tris/HCl, pH 8.8, 10 mM KCl, 8 mM MgSO₄, 10 mM (NH₄)₂SO₄, 0.1% Tween 20, 0.8M Betaine, 1.4 mM of each dNTP, 40 pmol of WSSV-FIP and -BIP primers, 5 pmol of WSSV-F3 and -B3 primers).
- ii) The primer sequences are WSSV-FIP: 5'-GGG-TCG-TCG-AAT-GTT-GCC-CAT-TTT-GCC-TAC- GCA-CCA-ATC-TGT-G-3', WSSV-BIP: 5'-AAA-GGA-CAA-TCC-CTC-TCC-TGC-GTT-TTA-GAA-CGG-AAG-AAA-CTG-CC-TT-3', WSSV-F3: ACG-GAC-GGA-GGA-CCC-AAA-TCG-A-3', WSSV-B3: 5'-GCC-TCT-GCA-ACA-TCC-TTT-CC-3'.
- iii) Heat the mixture at 50°C for 5 minutes and at 95°C for 5 minutes, then chill on ice, and add 1 µl (8 U) of *Bst* DNA polymerase.
- iv) Incubate the mixture at 65°C for 60 minutes, and then terminate the reaction at 80°C for 10 minutes.
- v) To visualise, electrophorese 2 µl LAMP reaction products on 2% agarose gels containing ethidium bromide at a concentration of 0.5 µg ml⁻¹. This reaction produces WSSV-specific LAMP products with multiple bands of various sizes from approximately 200 bp to the loading well.

Reliable LAMP commercial kits may be an alternative for WSSV diagnosis.

4.3.1.2.5. Agent purification

The WSSV virion can be purified as described previously with slight modifications (Xie *et al.*, 2005). Briefly, collect five or six moribund crayfish or shrimp (20–25 g each) at 3 days to 1 week post-infection. Homogenise all tissues excluding the hepatopancreas for 2 minutes using a mechanical homogeniser in 1200 ml TNE buffer (50 mM Tris/HCl, 400 mM NaCl, 5 mM EDTA, pH 8.5) containing protease inhibitors (1 mM phenylmethylsulfonyl fluoride, 1 mM benzamidine, and 1 mM Na₂S₂O₅). Centrifuge at 3500 **g** for 5 minutes. Save the supernatant and rehomogenise the pellet in 1200 ml TNE buffer. Filter the pooled supernatant through a nylon net (400 mesh) and centrifuge at 30,000 **g** for 30 minutes. Discard the supernatant and carefully rinse out the upper loose layer (pink) of the

pellet using a Pasteur pipette. Resuspend the lower compact layer (grey) in 10 ml TM buffer (50 mM Tris/HCl, 10 mM MgCl₂, pH 7.5). Pool the crude virus suspension and centrifuge at 3000 **g** for 5 minutes. Centrifuge the supernatant again at 30,000 **g** for 20 minutes. Remove the supernatant and pink loose layer and resuspend the white pellet in 1.2 ml TM buffer containing 0.1% NaN₃. Transfer to a 1.5-ml Eppendorf tube. Centrifuge the suspension three to five times at 650 **g** for 5 minutes each time to remove pink impurities. Finally, store the milk-like pure virus suspension at 4°C until use.

4.3.2. Serological methods

None developed.

5. Rating of tests against purpose of use

The methods currently available for targeted surveillance and diagnosis of infection with WSSV are listed in Table 5.1. The designations used in the Table indicate: a = the method is the recommended method for reasons of availability, utility, and diagnostic specificity and sensitivity; b = the method is a standard method with good diagnostic sensitivity and specificity; c = the method has application in some situations, but cost, accuracy, or other factors severely limits its application; and d = the method is presently not recommended for this purpose. These are somewhat subjective as suitability involves issues of reliability, sensitivity, specificity and utility. Although not all of the tests listed as category A or B have undergone formal standardisation and validation, their routine nature and the fact that they have been used widely without dubious results, makes them acceptable.

Table 5.1. Methods for targeted surveillance and diagnosis

Method	Targeted surveillance				Presumptive diagnosis	Confirmatory diagnosis
	Larvae	PLs	Juveniles	Adults		
Gross signs	d	d	c	c	c	d
Bioassay	d	d	d	d	c	b
Wet mounts and smears	d	d	c	c	c	d
Histopathology	d	c	c	c	a	c
Transmission EM	d	d	d	d	d	a
Antibody-based assays	d	d	c	c	a	b
<i>In-situ</i> DNA probes	d	d	c	c	a	a
Real-time PCR	c	b	a	a	a	a
Conventional PCR	d	c	b	b	b	a
LAMP	d	d	a	a	a	a
Sequence	d	d	d	d	d	a

PLs = postlarvae; LM = light microscopy; EM = electron microscopy;
PCR = polymerase chain reaction; LAMP = loop-mediated isothermal amplification.

6. Test(s) recommended for targeted surveillance to declare freedom from infection with white spot syndrome virus

Real-time PCR is the recommended test for targeted surveillance to declare freedom from infection with white spot syndrome virus.

7. Corroborative diagnostic criteria

7.1. Definition of suspect case

Infection with WSSV is suspected if at least one of the following criteria is met:

1. Gross pathology consistent with infection with WSSV
2. Histopathology consistent with infection with WSSV
3. Positive conventional PCR result
4. Positive real-time PCR result
5. Positive LAMP result

7.2. Definition of confirmed case

Infection with WSSV is considered to be confirmed if one or more of the following criteria are met:

1. Histopathology consistent with WSSV and positive *in-situ* hybridisation test
2. Positive conventional PCR results and conventional PCRTargeting different region of the WSSV genome with sequence analysis consistent with WSSV
3. Positive real-time PCR results and conventional PCR targeting different region of the WSSV genome with sequence analysis consistent with WSSV
4. Positive LAMP results and conventional PCR targeting different region of the WSSV genome with sequence analysis consistent with WSSV

8. References

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NB: There are OIE Reference Laboratories for infection with white spot syndrome virus (see Table at the end of this *Aquatic Manual* or consult the OIE web site: <https://www.oie.int/en/what-we-offer/expertise-network/reference-laboratories/#ui-id-3>). Please contact the OIE Reference Laboratories for any further information on infection with white spot syndrome virus

NB: FIRST ADOPTED IN 1997 AS WHITE SPOT DISEASE. MOST RECENT UPDATES ADOPTED IN 2018.